VERIFICATION OF FLEET NUMERICAL WEATHER CENTRAL WAVE ANALYSES

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THESIS

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by

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Verification of Fleet Numerical

Weather Central Wave Analyses

by

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ABSTRACT

Fleet Numerical Weather Central (FNWC) wave period and height analyses for a selected grid point were verified by comparison with wave conditions recorded by a coastal wave sensor at San Clemente Island, California. Forty-six per cent of the FNWC wave heights were within ±1 foot of the recorded heights, 75% were within ±2 feet, and 92% were within ±4 feet. The FNWC heights were found to be over-predicted by 1.0 feet relative to the recorded waves. Twenty-six per cent of the FNWC periods were within ±1 second of the recorded periods, 45% were within ±2 seconds, 66% were within ±4 seconds, and 90% were within ±6 seconds. There was no tendency for FNWC to over or underpredict swell periods, but wind-wave periods were underpredicted on the average by five seconds.

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I. INTRODUCTION

A. OBJECTIVE

The purpose of this thesis is to verify the wave height and period analyses produced by the Fleet Numerical Weather Central, Monterey (FNWC) by comparing the FNWC analyses with the wave conditions recorded by a coastal wave sensor. Specifically, this thesis presents the results of a study to determine by how much and in what ways the FNWC analyses differ from actual observations.

B. VERIFICATION APPROACH

The coastal wave gage used was a pressure-type sensor located in 40 feet of water off the northwest end of San Clemente Island (Figure 1). The instrument is located on the bottom and records both wind waves and swell waves. The wave data are recorded on paper tape or strip chart. A manual analysis was performed to obtain wave period and height information from these strip chart records on a six-hourly basis.

The FNWC wave analyses yield deep-water wave conditions at a grid point on their 63 x 63 Northern Hemisphere grid. The analyses consist of significant or dominant period, significant height, and direction of the wind waves and dominant swell waves present. The waves are forecasted from the FNWC surface pressure analysis, using the Sverdrup-Munk-Bretschneider Wave Model adapted for numerical use by

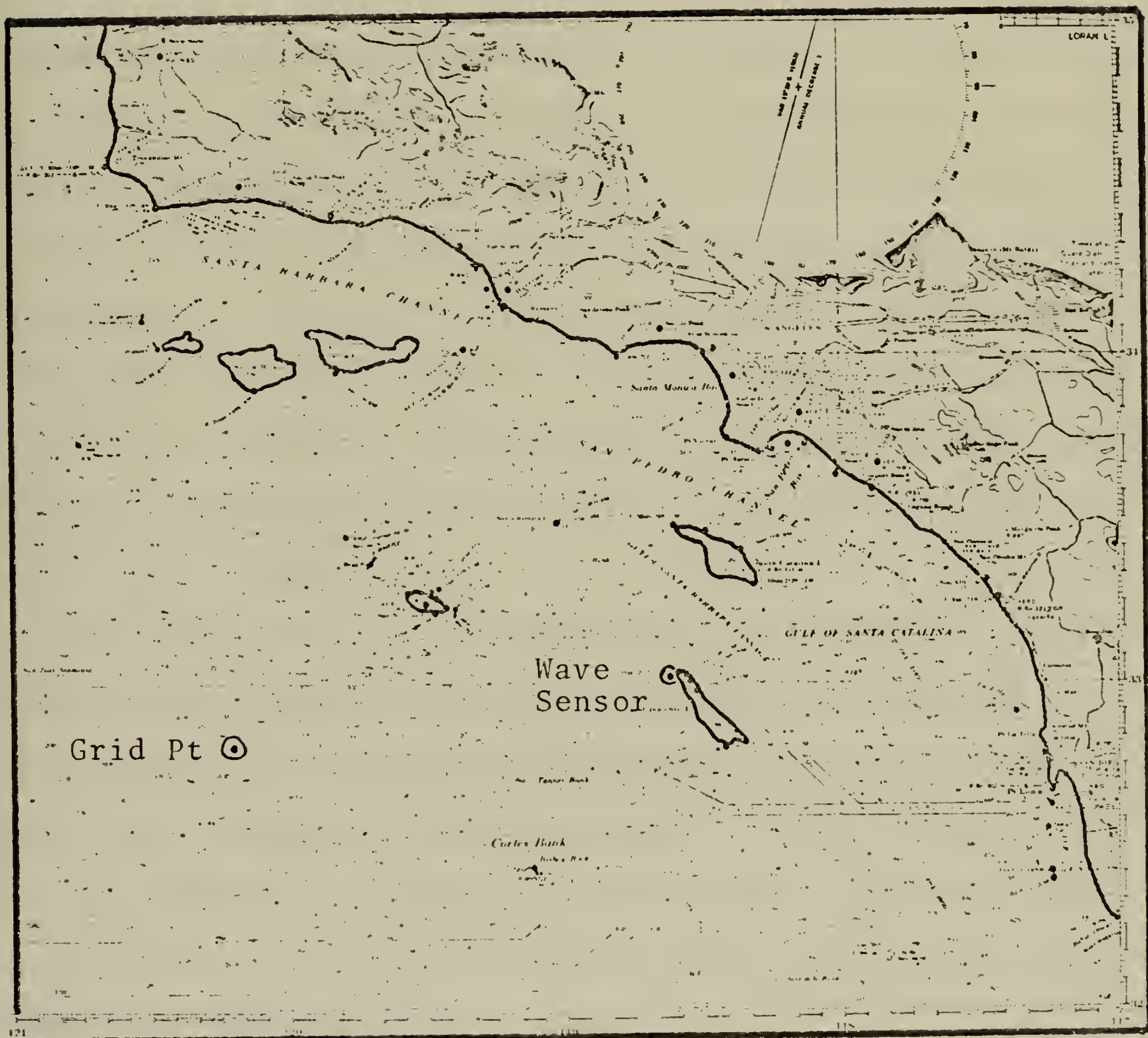

Figure 1: Location of San Clemente Island wave sensor and FNWC grid point (C. & G. S. Chart No. 5020)

FNWC. The deep-water wave conditions are computed on a twelve-hourly basis. The grid point for which the FNWC analyses were made was located 79 miles west of the San Clemente wave sensor site. This grid point was selected for use at the beginning of the study because it was the closest grid point to the wave sensor site. However, the optimum way to verify the FNWC wave analyses by comparison with wave conditions at a shallow water site was to have the analyses prepared for the location of the wave sensor. This was originally considered but discarded because the FNWC computer program would have to be altered to interpolate between grid points. This decision created problems that will be discussed in detail later in this paper.

The FNWC wave analyses rather than the forecasts were used for verification. The wave analyses are produced by application of a wave-forecasting model to the observed wind field, whereas the wave forecast is made by applying the same model to a forecasted wind field. The wave forecasting model used is the Sverdrup-Munk-Bretschneider model adapted for numerical use by FNWC

In order to compare the FNWC waves with the observed waves under equivalent conditions, the FNWC deep-water waves were carried into shoal water to the wave-gage site. This was done by application of conventional shoaling and refraction corrections to the deep-water waves. These waves were further corrected to account for the depth of the wave sensor (40 feet) by application of a hydrodynamic damping

correction. The waves recorded on the bottom could not be conveniently transferred to the surface for comparison because the method used to determine the period from the wave records yielded a number of different periods from a given twenty-minute trace. In addition, refraction corrections could not be applied to the observed waves in reverse to take the waves from shallow water out to deep water because wave direction, which is needed to determine the refraction factor, cannot be determined from a single wave sensor.

Further, in order to perform verification, the FNWC wind-wave heights and swell-wave heights had to be combined because the wave sensor records only the combined heights of wind waves and swell and the latter cannot be separated into components. This combining of the wave heights was done by a root-mean-square procedure after both sets of waves were corrected separately for refraction, shoaling, and hydrodynamic damping.

Four problems arose during this thesis study that made verification of the FNWC wave analyses by use of coastal wave records difficult and which prohibited the use of some of the records. First, the wave-sensor site at San Clemente Island is largely surrounded by shoal areas which result in extensive refraction of waves from most directions. Second, difficulties were introduced because the grid point for which the FNWC wave analyses were made did not coincide with the sensor site. Third, the grid boundary and the size of the grid spacing are such that small-scale pressure and wind

patterns which affect the recorded wave conditions are not reflected in the FNWC analysis. Fourth, there was a problem in continuity of the wave records. Useful wave records were not obtained on a regular basis until a timer was installed in the wave-recorder system. These problems, all of which can be avoided in future work of this type, required considerable attention before valid comparisons between the FNWC analyses and the observed waves could be made.

II. SELECTION OF THE WAVE GAGE SITE

A. GENERAL REQUIREMENTS

In order to perform a satisfactory verification of analyzed or forecasted wave data by comparison with wave period and height data from a coastal wave sensor, the selection of a sensor site is an important and necessary consideration.

The ultimate objective in the selection of a site is to obtain data in large volume which is minimally affected by shoal water and the configuration of the coast and which is faithfully reproduced. In addition, the recorder should be placed as close to the surface as possible to minimize hydrodynamic filtering of the waves. Because of the absence of suitable structures in most coastal areas on which to mount a surface wave gage, most sensors are of the pressure type mounted on or near the bottom. Other considerations are that the recorder system must be dependable in its operation, that it must be calibrated, and that it should be adequately maintained so that repairs may be made when needed. Finally, the records should be annotated regularly and be in a form suitable for analysis by the method chosen.

B. SELECTION OF THE SAN CLEMENTE ISLAND GAGE

In order to perform wave verification of North Pacific waves, a wave recorder on the Pacific coast of the United States was needed. There were six known wave recorders on the Pacific coast in operation as of June 1971. Table I

TABLE I: WAVE RECORDER SITES ON THE PACIFIC COAST

RECORDER SITE	AGENCY	ADVANTAGES	DISADVANTAGES
1. San Clemente Island, California	Fleet Weather Facility, San Diego	1. Personnel are on watch at both the wave recorder and wave gage site at all times to discover and correct problems that occur in the recorder system, thus making the system more reliable. These personnel are also available to annotate the records regularly.	1. Wave gage is not in a good location to record swell from North Pacific storms. 2. Only a few narrow wave windows occur through which swell can reach the gage without refraction and shoaling through shallow water areas at some distance from the island. These windows are shown in Figure 2.
2. Huntington Beach, California	National Weather Service, Los Angeles	1. Wave recorder is used to forecast local wind wave conditions in Southern California.	1. Wave gage is in a poor location for use in a verification study of both North Pacific swell and wind waves from most directions. 2. Only wave windows are: a. 159° to 197°. b. 261° to 275° with shoal areas for long period waves.

TABLE I: (CONTINUED)

RECORDER SITE	AGENCY	ADVANTAGES	DISADVANTAGES
3. Pt. Mugu, California	Weather Detachment, Pacific Missile Range, Pt. Mugu	1. Personnel are on watch at all times to maintain the equipment and to annotate the wave records regularly.	1. Wave gage is not in very good location for use in a verification study. 2. Only wave windows are: a. 160° to 186° with shoal areas for long-period waves. b. 214° to 236° with the long-period waves. c. 275° to 285°.
4. Monterey California	Naval Postgraduate School, Monterey	1. Wave recorder system is very reliable. 2. Wave recorder is constantly checked for any problems that may arise, and better control of the operation of the system can be maintained by the school itself.	1. Recorder system was temporarily out of operation until September 1971. 2. Refraction is complicated by multiple shoaling of waves from the northwest quadrant. 3. Swell from the south and southwest refracts greatly around the Monterey Peninsula.

TABLE I: (CONTINUED)

RECORDER SITE	AGENCY	ADVANTAGES	DISADVANTAGES
5. Santa Cruz California	Corps of Engineers, San Francisco Branch	1. Wave recorder system is fairly reliable. 2. Site has open wave windows to the south and southwest for swell from the Southern Hemisphere.	1. Wave gage is in a poor position to record swell from North Pacific storms because there is large refraction for most wave directions. Swell from the north and northwest will shoal far up the coast, then must refract around the northern edge of Monterey Bay to reach the wave gage site.
6. Newport Oregon	Oregon State University, Corvalis, Oregon	1. Wave gage is in a completely open position to record swell from all North Pacific storms. 2. Refraction effects seaward of the wave sensor are relatively minor compared to the other wave gage sites.	1. Wave recorder system was installed and became inoperable in August 1971, and could not feasibly be repaired at that time.

is a list of these wave recorders and the advantages and disadvantages of each for the purpose of wave verification.

The wave recorder system at Newport, Oregon was initially selected as the source of wave records for comparison with the FNWC analyses because it was located in the best position to record swell from North Pacific storms and also because the refraction problem was minor compared to other locations. The system was put into operation in August 1971, and refraction diagrams for the area of the sensor site were prepared. A few weeks later, the system became inoperative and could not be repaired in sufficient time to be of use in this study.

As a result, the San Clemente Island wave recorder system was the next best choice. Personnel were on watch at all times to adequately maintain the system and to annotate the records regularly.

C. PROBLEMS ENCOUNTERED WITH THE SAN CLEMENTE RECORDER

1. Wave Record Problem

A minimum of twenty minutes of fast-speed trace is needed to perform a satisfactory period and height analysis of wave records. In order to conserve recorder paper, the usual procedure is to record at a fast speed for twenty minutes every six hours with the remainder of the records being recorded on slow speed. This programming was to be performed by the technician on watch but resulted in irregular and unpredictable timing for the wave records. An industrial

timer, provided by the Naval Postgraduate School, was subsequently installed in the recorder system. This automatically programmed the timing to give a fast trace coincident with each synoptic weather-map time (0000Z, 0600Z, 1200Z, and 1800Z) for a twenty-minute period. After installation, additional loss of records occurred when the equipment malfunctioned, the timer was accidentally cut out of the system, or the microwave interference in the signal transmitted from the sensor on San Clemente Island to the recorder on North Island caused it to be impossible to make an analysis.

2. Problems of Wave Refraction and Shoaling

Examination of Figure 1 shows that offshore banks, islands, and part of the mainland coast severely limit the unobstructed arrival of swell from the open ocean at San Clemente Island. The effect of these features on waves arriving in deep water immediately off the sensor site is presented graphically in Figure 2. The area inside the curve shows those swell periods that will arrive at the sensor site unaffected by refraction. Those periods that are affected by refraction are located outside the curve. It may be seen that long-period swell from all directions, except the south-southwest quadrant must refract over offshore areas to get to the wave sensor site. All swell from the north-northwest sector must refract around the Channel Islands. Swell from the west may arrive at the recorder unaffected, but swell from west-southwest must refract and shoal across a series of offshore banks.

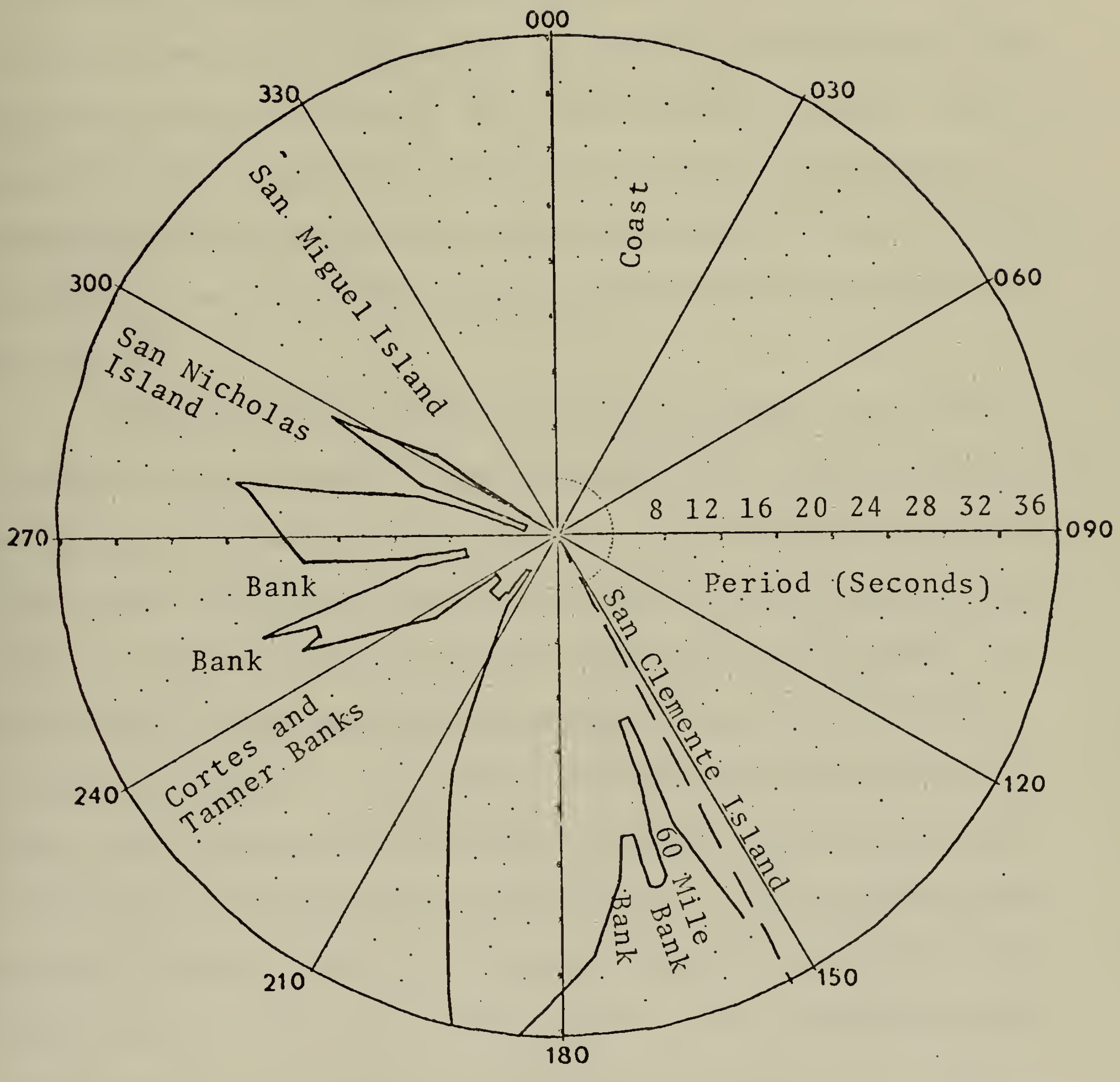

Figure 2: Shoaling effects for San Clemente Island wave sensor site for seaward wave directions of 153° - 348°.

Thus, the refraction situation around San Clemente Island is a complicated one and demonstrates that the wave recorder is not in a desirable location to record all waves from the open ocean that might be present; accordingly, the wave data are not the best for a verification study. The unsatisfactory character of this wave sensor site from a standpoint of applying refraction modifications over distant shoal areas was not fully appreciated until the study was well along.

Due to the fact that refraction around San Clemente Island is complicated, it was felt that the task of preparing the necessary refraction diagrams for all of the surrounding shoal water areas would be well beyond the province of this study. Also, an additional uncertainty would be added to the quality of the wave data corrected for these distant refraction effects. As will be discussed in more detail later, only those swell data not affected by refraction at a distance from San Clemente Island (i.e., only those swell periods located inside the curve in Figure 2) were used for verification. The latter were in all cases corrected for refraction and shoaling in traversing the short distance across the island shelf to the wave sensor site.

III. ANALYSIS OF SAN CLEMENTE ISLAND WAVE RECORDS

A. GENERAL ANALYSIS SCHEME

The analyses for significant wave height and significant or dominant wave period were performed on fast-trace portions of the wave records. In order to obtain a representative analysis of the wave conditions prevailing, it is generally considered that the duration of the fast trace should be a minimum of twenty minutes to insure that short-term wave variability is reduced to a minimum.

The wave records received from Fleet Weather Facility, San Diego were in the form of strip-charts recorded on a Varian Recorder from a pressure-type wave gage. The data were recorded at both a slow speed of three inches per hour and a fast speed of two inches per minute. The recorder was programmed to produce a fast-speed record for twenty minutes every six hours. Analysis of period can only be made on the fast-trace record, but height can be determined from either fast or slow trace records, although the former is preferable. The heights that may be selected for recording are five feet, ten feet, or 20 feet across the full scale. The chart scale used throughout this study was ten feet. An example of a fast-trace record is shown in Figure 3.

The period covered by the San Clemente Island wave records was October 29, 1971, to January 1, 1972. The analysis was performed on fast-trace records until December 21, 1971, after which only slow-trace records were available. Height analysis,

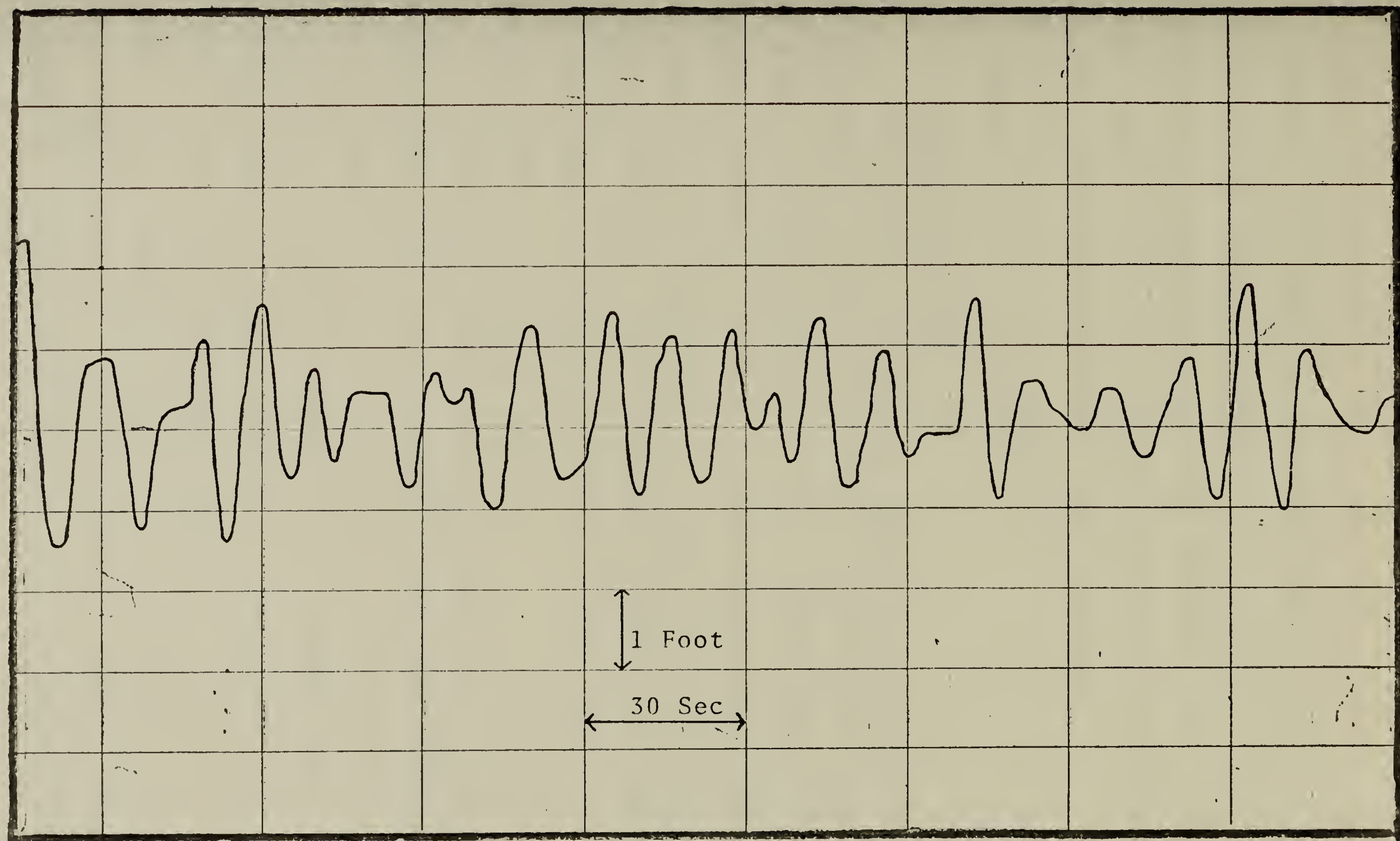

Figure 3: Example of a fast-trace wave record.

but no period analysis, was performed on these slow-trace records.

The wave records from the San Clemente Island recorder were analyzed manually rather than spectrally. Manual analysis was chosen because it was believed that a significantly larger number of wave records could be analyzed in the time available with about equal accuracy.

B. MANUAL ANALYSIS PROCEDURES

1. Period Analysis

The period analysis was performed by use of the wave-group method in which the period of identifiable wave sequences or groups occurring during a twenty-minute fast trace were measured [Thompson, 1970]. The wave period was determined by measuring the time interval between the first and last well-defined wave in the group and dividing the time interval by the number of waves in the group. The result is a single period value for the wave group.

As many as nine different values were obtained from a twenty-minute fast trace, some denoting local wind waves when present and some denoting swell. Those wave groups with periods relatively close to one another (one or two seconds apart) were considered to be members of the same wave train. When two or more wave trains were present at the same time, the periods denoting each could sometimes be distinguished from the analysis of the wave records. Swell trains were frequently readily identified by their characteristic period decrease with time.

For each twenty-minute fast trace the dominant period, i.e., the period of the wave group of greatest height, was singled out. This was the period that was used as the verification period for the FNWC waves.

2. Height Analysis

a. Fast-Trace Analysis

The significant height was obtained from each twenty-minute fast trace by a quick, simple procedure suggested by W. C. Thompson (personal communication). The procedure is based on the observation that any arbitrarily selected statistical amplitude parameter has a mean constant frequency of occurrence for any wave train, as given in Tables 1.1 and 1.2 of H.O. 603, e.g., $A_{60\%} = 0.71\ E^{1/2}$, and on the further observation that the ratio between any selected amplitude parameter and the significant amplitude (average amplitude of the one-third highest waves) is also a constant (e.g., $\frac{A_{60\%}}{A_s} = \frac{0.71\ E^{1/2}}{1.416E^{1/2}} = 0.502$, where $A_s = 1.416E^{1/2}$). From these considerations then, it was possible to construct Figure 4.

The analysis is performed as follows:

(1) Determine the centerline of the recorded waves on the wave record, i.e., the position on the strip chart of the mean water level, by visual observation.

(2) Choose by visual inspection an arbitrary value of wave amplitude such that between 20% and 50% of the total number of the wave amplitudes in the twenty-minute

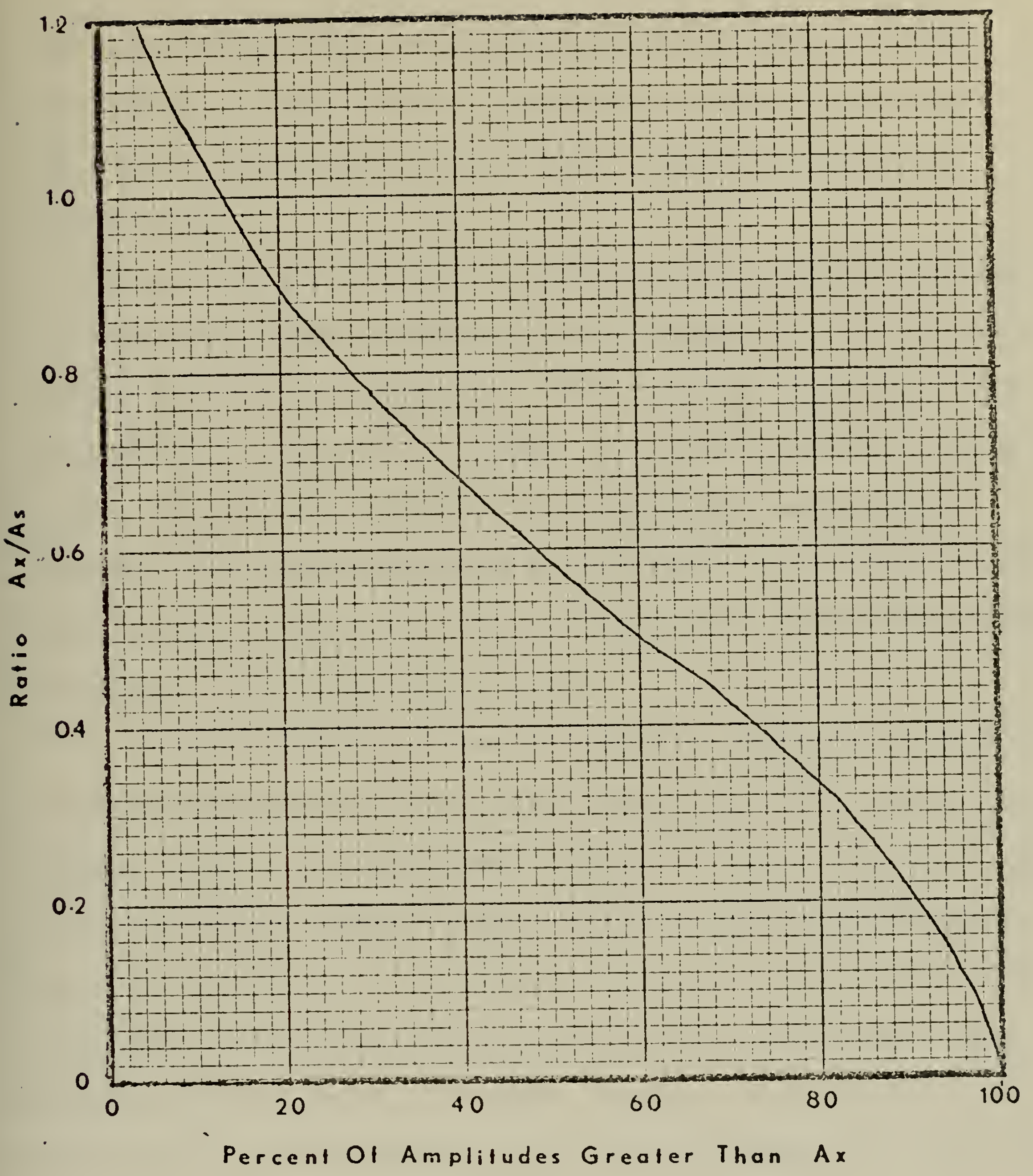

Figure 4: Ratio of A_x/A_s for values of A_x.

record exceed that arbitrary amplitude value. This arbitrary value will be denoted by the term A_x. Count the number of waves whose amplitude exceeds A_x and determine their percentage to the total number of waves in the record.

(3) Enter the graph shown in Figure 4 with the percentage of amplitudes that exceeded A_x and obtain a value of the ratio A_x/A_s on the ordinate. The term A_s represents the significant amplitude. Compute A_s from A_x and the value of A_x/A_s. A_s is obtained for both the crest and trough, because the crest amplitude is observed to commonly exceed the trough amplitude, and the two values are added together to obtain the significant height.

In several of the fast-trace records the results of the height analysis using the method described above were compared with the conventional method of measuring the heights of the one-third highest waves in the record and averaging them. The results of the comparison showed that the height values were almost the same in all cases. Since the two methods produced nearly the same results, the conventional method was not used because it is time-consuming in comparison.

b. Slow-Trace Analysis

This analysis requires estimating visually an amplitude, called $A_{67\%}$, such that one-third of the waves present in the slow trace exceed this amplitude [Thompson, 1970]. The crest and trough amplitudes were estimated in the same manner and then summed to give $H_{67\%}$. The significant height was

then calculated by use of the relationship, $H_s = 1.35\ H_{67\%}$. This relationship is derived from Tables 1.4 and 1.5 of H.O. 603 [Pierson, Neumann, and James, 1955], where $H_s = 2.83\ E^{1/2}$ and $H_{67\%} = 2.10\ E^{1/2}$. Approximately one-hour intervals of the wave records were analyzed using this procedure.

As was stated previously, this method was used only when fast-trace records were not recorded. Its accuracy is not considered to be as good as the fast-trace method because it is based on a visual estimate of the amplitude exceeded by one-third of the waves. The advantage to this method is that it covers a longer period of time than the fast-trace method and thereby allows the wave heights to average out over the record. It is a fast, time-saving method which involves no counting of waves.

C. PRESENTATION OF RESULTS OF THE ANALYSIS

The results of manual analysis of the San Clemente Island wave records were plotted on a common graph in the form of significant wave height and wave group frequency versus time, and are shown in Figures 5 through 10. The dominant frequency from each wave record is denoted on the graphs by a square. Frequency values were plotted on the graph instead of period values because frequency is considered a more useful parameter. The analysis results were plotted for every six-hour time period corresponding to the synoptic times. At those synoptic times where no values were plotted, fast-trace wave records were not available.

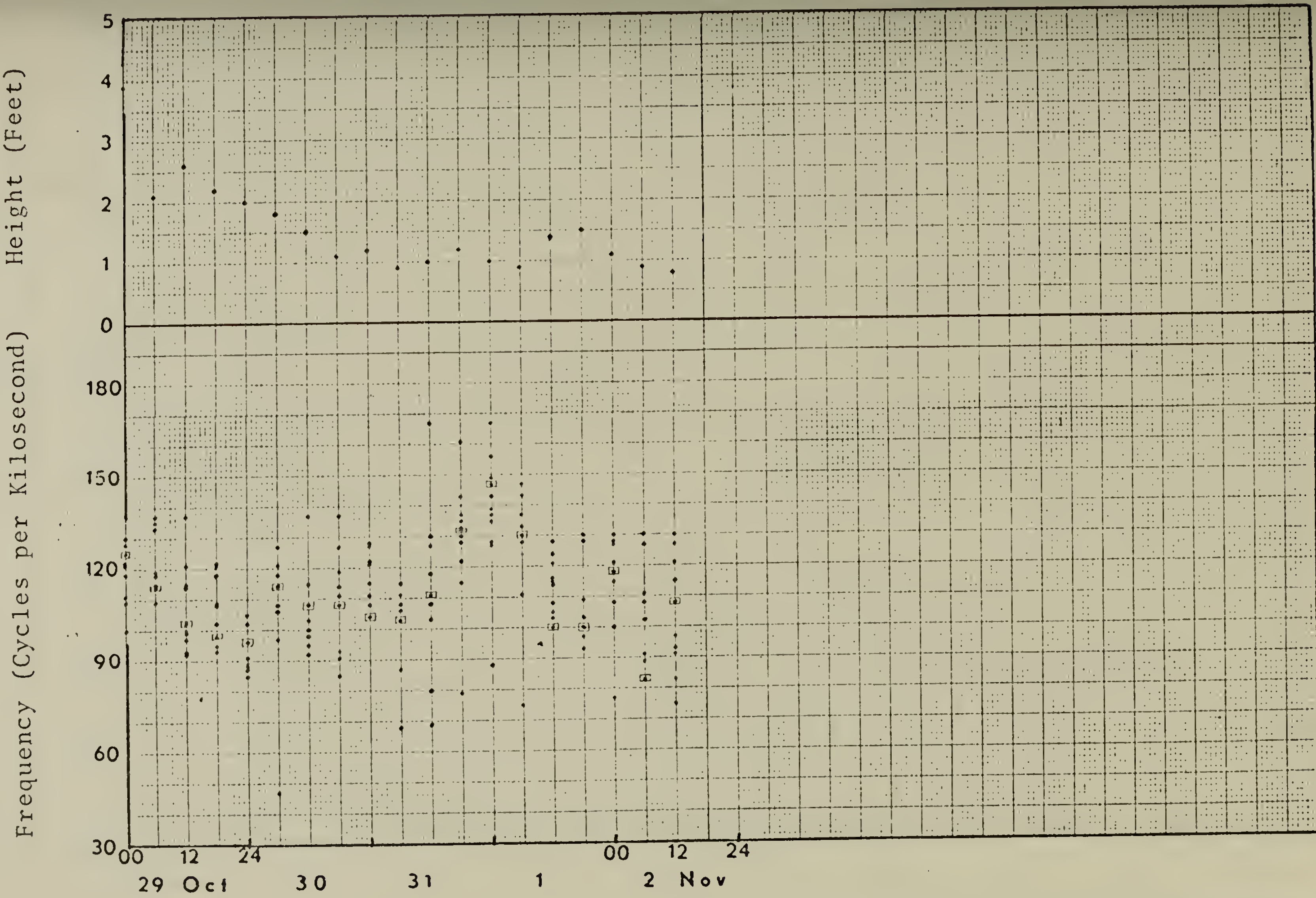

Figure 5: Results of wave record analyses (Squares denote dominant frequency).

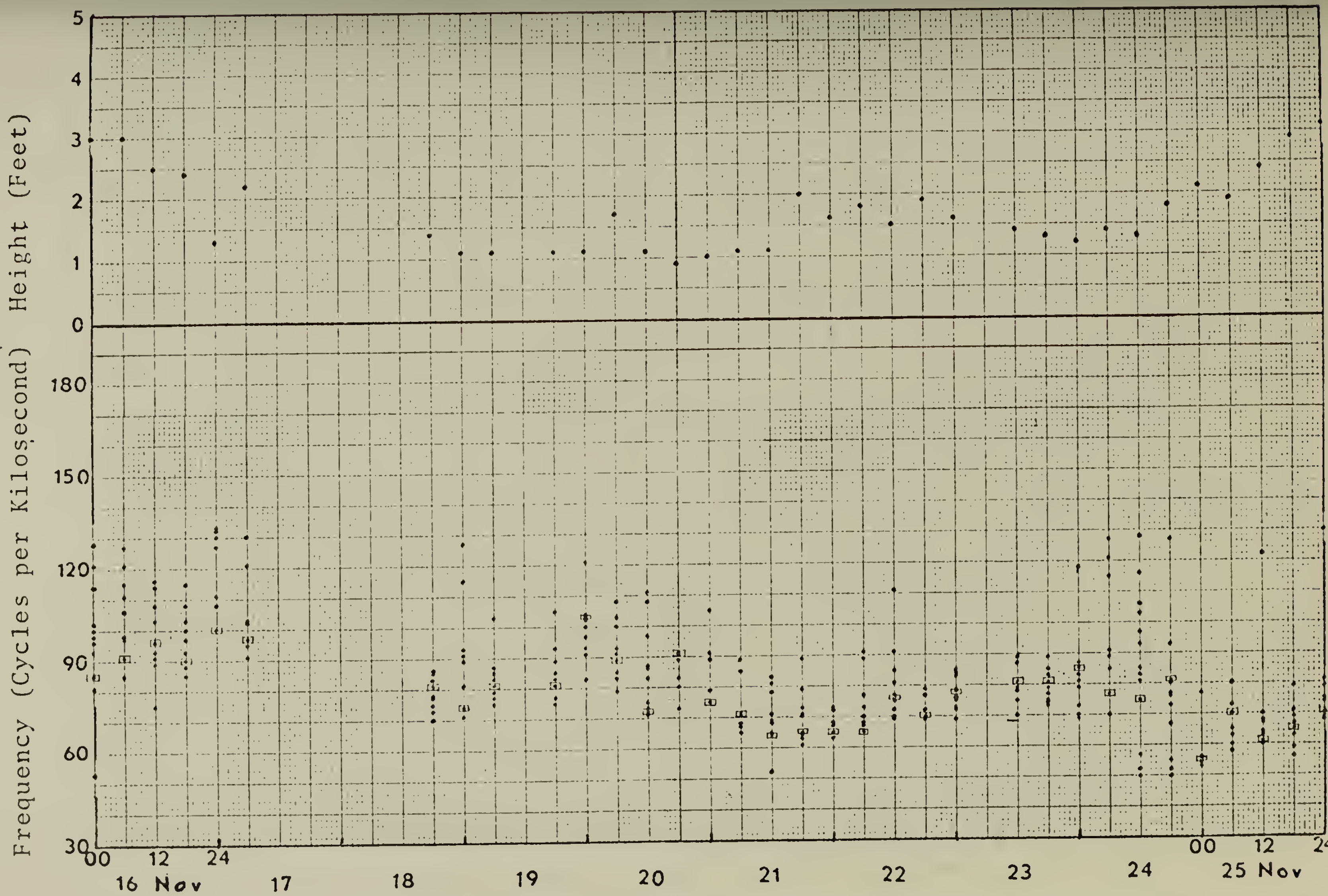

Figure 6: Results of wave record analyses (Squares denote dominant frequency).

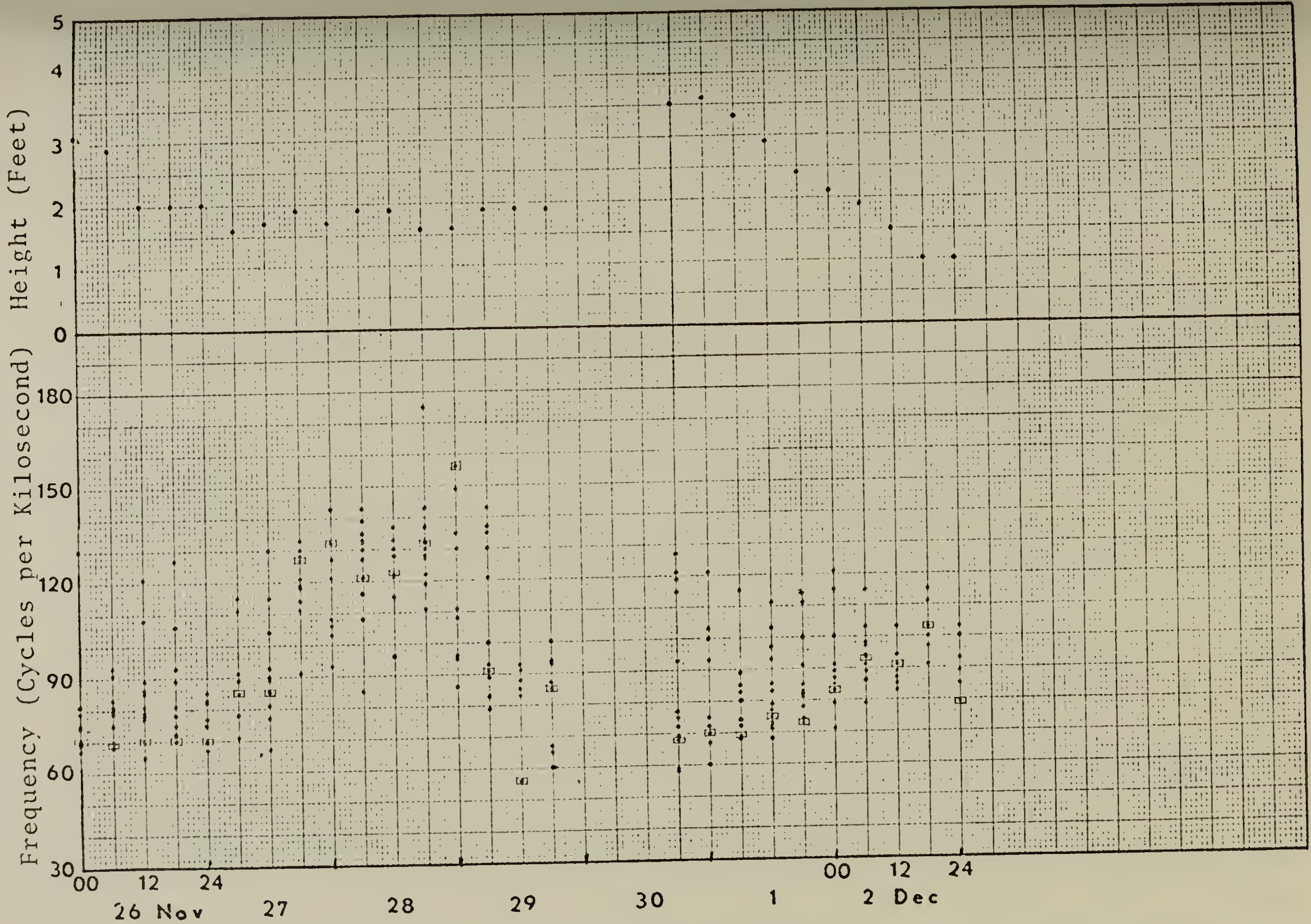

Figure 7: Results of wave record analyses (Squares denote dominant frequency).

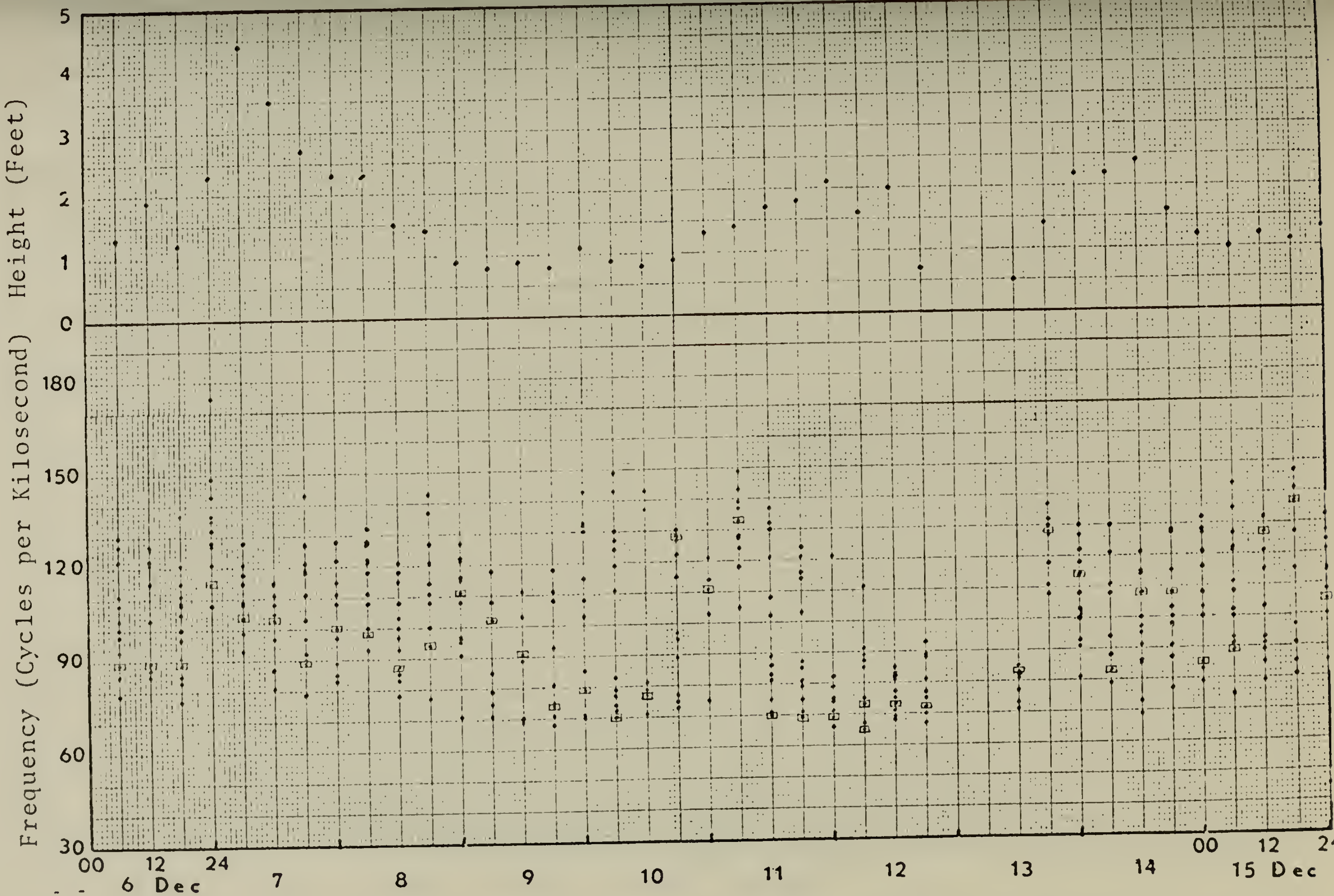

Figure 8: Results of wave record analyses (Squares denote dominant frequency).

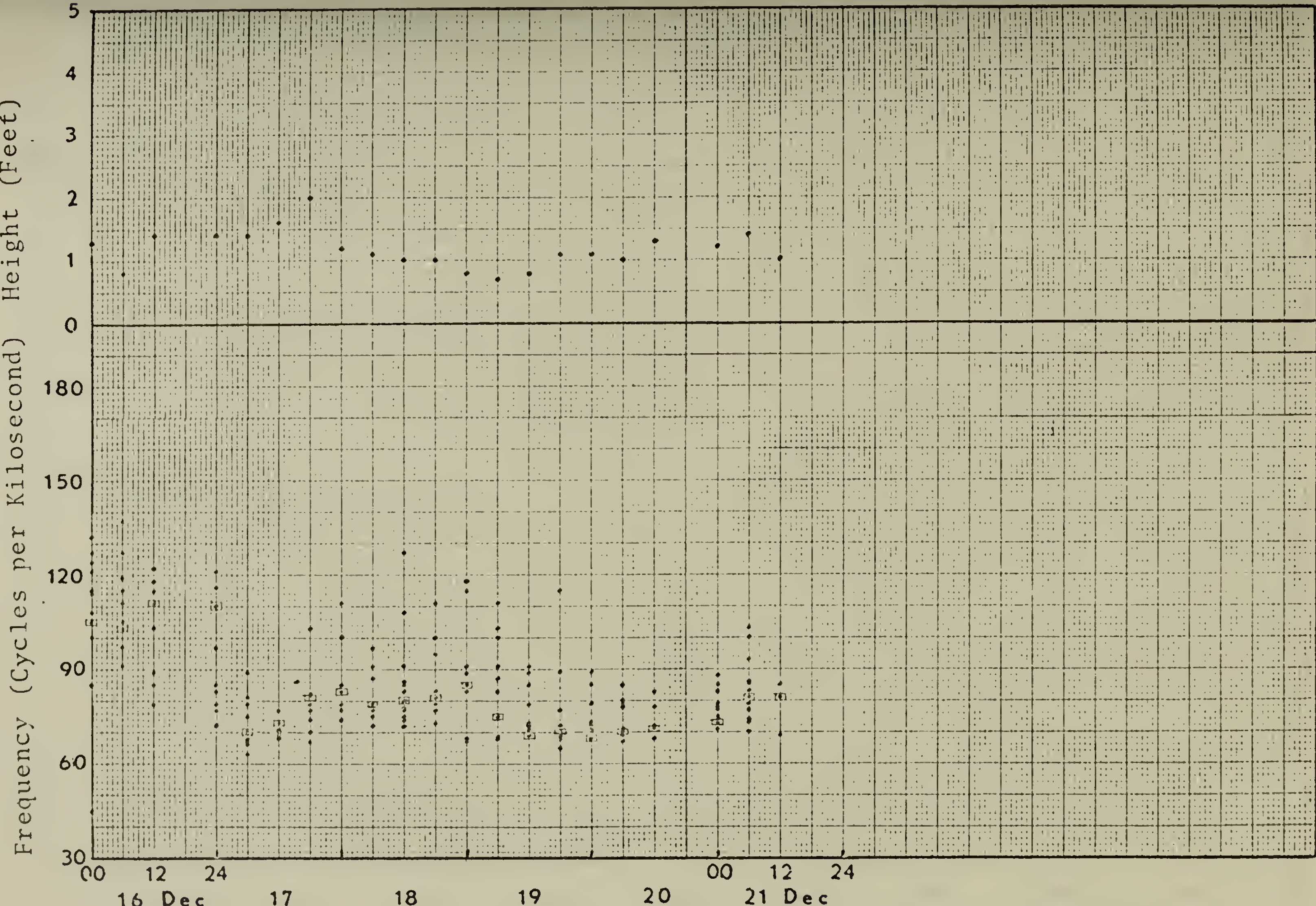

Figure 9: Results of wave record analyses (Squares denote dominant frequency).

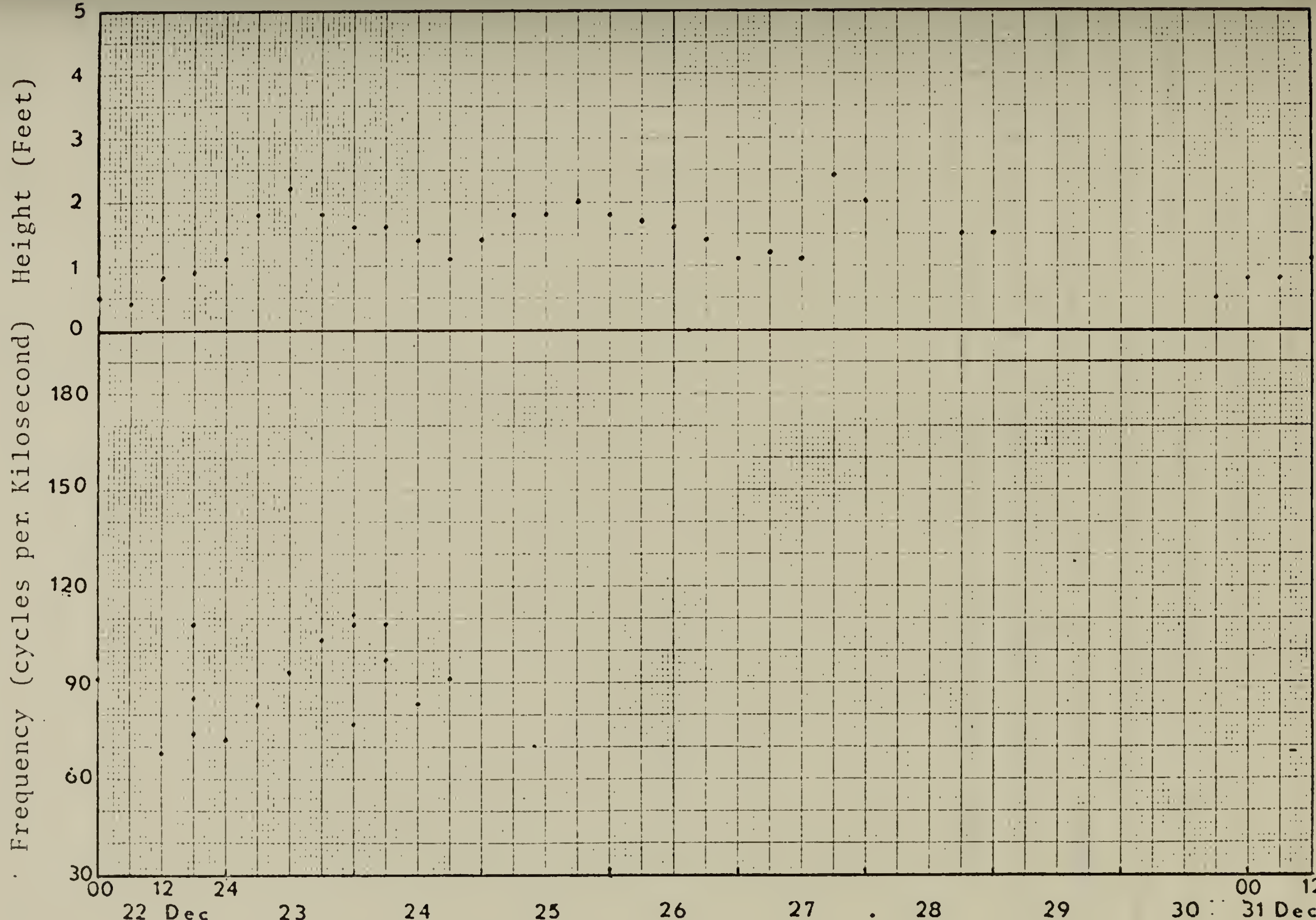

Figure 10: Results of wave record analyses

The information presented in Figures 5 through 10 constitutes the basic wave data used in the verification of the FNWC wave analyses. From examination of the time distribution of wave frequency, and of the frequency and height considered together, it was possible at times to distinguish between wind waves and swell in the wave record. Swell is readily identified and distinguished from wind waves by a linear frequency-time (f-t) distribution where the frequency increases with time.

IV. FNWC WAVE ANALYSES

A. GENERAL FNWC ANALYSIS SCHEME

The FNWC wind wave and swell analysis model is based on the Sverdrup-Munk-Bretschneider wave forecasting method [Bretschneider, 1952], and is described by Hubert and Mendenhall [1970]. It is a singular model in that the wave conditions are computed for a series of individual points on a grid. The model gives both wind wave and swell analyses which are based on the observed surface pressure field, and wind wave and swell forecasts which are based on the forecasted surface pressure field. Only the analyses were used in this verification study. The FNWC wave analysis is computed from the observed surface pressure field, not from actual wave observations.

The FNWC wave model also provides for the propagation of swell. It assumes that swell decays in a zero wind field, i.e., there is no subsequent wind effect to enhance further growth or inhibit decay. The model decays swell along great-circle paths with a logarithmic reduction of height and a logarithmic increase in the period of maximum energy. The model also initiates swell along a great-circle track from each grid point if its wind-wave height is five feet or more. A continuous swell history is maintained until the swell decays to less than three feet, reaches land or ice, or travels off the grid.

The swell wave conditions reported in the FNWC printout are those of the dominant swell train. A secondary swell train that may be present is not included in the output of the program; however, it is not terminated within the program because it may be dominant at another grid point at a later time.

B. FNWC WAVE ANALYSIS OUTPUT

In order to perform a verification of the FNWC wave data, it was necessary to obtain the FNWC analyses for a location near the San Clemente Island wave sensor. The FNWC wave data used for verification in this study were the analyses for the grid point I-20, J-18, on the FNWC 63 x 63 Northern Hemisphere grid. This grid point is located 79 nautical miles west of (bearing 260° from) the San Clemente Island wave sensor site, as can be seen in Figure 1. The wave data provided for the grid-point location were the significant height (to 0.1 foot), the period (to 0.1 second), and the mean direction (to 1 degree) for both wind waves and the dominant swell train every 12 hours at the synoptic reporting times of 0000Z and 1200Z. Figure 11 is an example of the FNWC computer printout of the analyzed wave data.

C. MODIFICATIONS TO FNWC WAVE DATA

1. Shoal-Water Corrections

As stated above, in order to compare the analyzed waves with observed waves under a common set of conditions,

NEWPORT, SAN CLEMENTE WAVES AND SWELL FOR 71120700

NEWPORT	WH(FT)	WP(SEC)	WD(DEG)	SH(FT)	SP(SEC)	SD(DEG)
0	6.2	6.6	335	5.9	10.2	263
12	2.5	4.0	41	4.2	7.9	332
24	3.7	5.0	132	3.5	13.2	291
36	9.9	7.9	172	3.6	13.4	288
48	17.0	11.0	170	5.1	8.3	172

SAN CLEMENTE	WH(FT)	WP(SEC)	WD(DEG)	SH(FT)	SP(SEC)	SD(DEG)
0	8.3	7.4	330	2.0	5.9	9
12	12.0	8.8	328	3.9	8.5	354
24	17.9	11.1	339	9.4	11.1	352
36	17.8	10.7	331	12.8	14.5	358
48	10.2	6.5	313	15.4	15.9	359

Figure 11: Example of FNWC wave analysis printout.

the FNWC wave data were modified, whereas no modifications were made to the wave recorder data. The modifications were made to the FNWC data rather than to the recorded data because wave directions which are necessary for computing the refraction factor cannot be obtained from the recorded wave data. Also each analyzed wave record of twenty-minute duration yields several different period values which would present the problem of choosing which of several different refraction, shoaling, and hydrodynamic damping factors should be applied to the single wave-height value obtained from the analysis. The FNWC deep-water wave conditions were transferred to the shallow-water position of the wave sensor by applying refraction, shoaling and hydrodynamic damping corrections. Deep-water waves traversing shoal water can also be affected by bottom friction and percolation over a sandy bottom. These two factors were not taken into account in this study, as it was assumed that their effects in reducing the wave energy are negligible over the narrow island shelf.

a. Height Corrections

The FNWC wave heights were modified to shallow-water conditions at the wave sensor site by use of the equation:

$$H_{SENSOR} = H_{GRID\ PT}\ (K_r\ K_s\ K_d)$$

where H = wave height

K_r = refraction factor

K_s = shoaling factor

K_d = hydrodynamic damping factor

(1) Refraction Factor. The refraction process describes the bending of the wave rays or orthogonals as they enter shoal water, and the effect of convergence or divergence of the orthogonals on the wave heights. The refraction factor, K_r, is defined as:

$$K_r = \left(\frac{bo}{b}\right)^{1/2}$$

where: b_o = ray separation in deep water

b = ray separation at the wave gage

Refraction diagrams were constructed for the shoal water area around San Clemente Island surrounding the wave gage site and were drawn using the numerical procedure of Griswold [1963]. For this study, 54 refraction diagrams were drawn for nine deep-water wave directions (N, NNW, NW, WNW, W, WSW, SW, SSW, and S) and six periods (6, 9, 12, 15, 18, and 21 seconds).

Computation of the refraction information required that the depth field first be extracted from a sufficiently detailed bottom chart of San Clemente Island. The chart used was C. & G. S. Chart No. 5111. A grid was drawn over the area having a grid spacing such as to include all significant depth changes. The grid was a 36 x 84 rectangular grid with a grid spacing of 1,200 feet. The grid covered a geographical area of approximately 4.5 nautical miles to the west, 6.6 nautical miles to the north, and 10.6 nautical miles to the south from the wave sensor location.

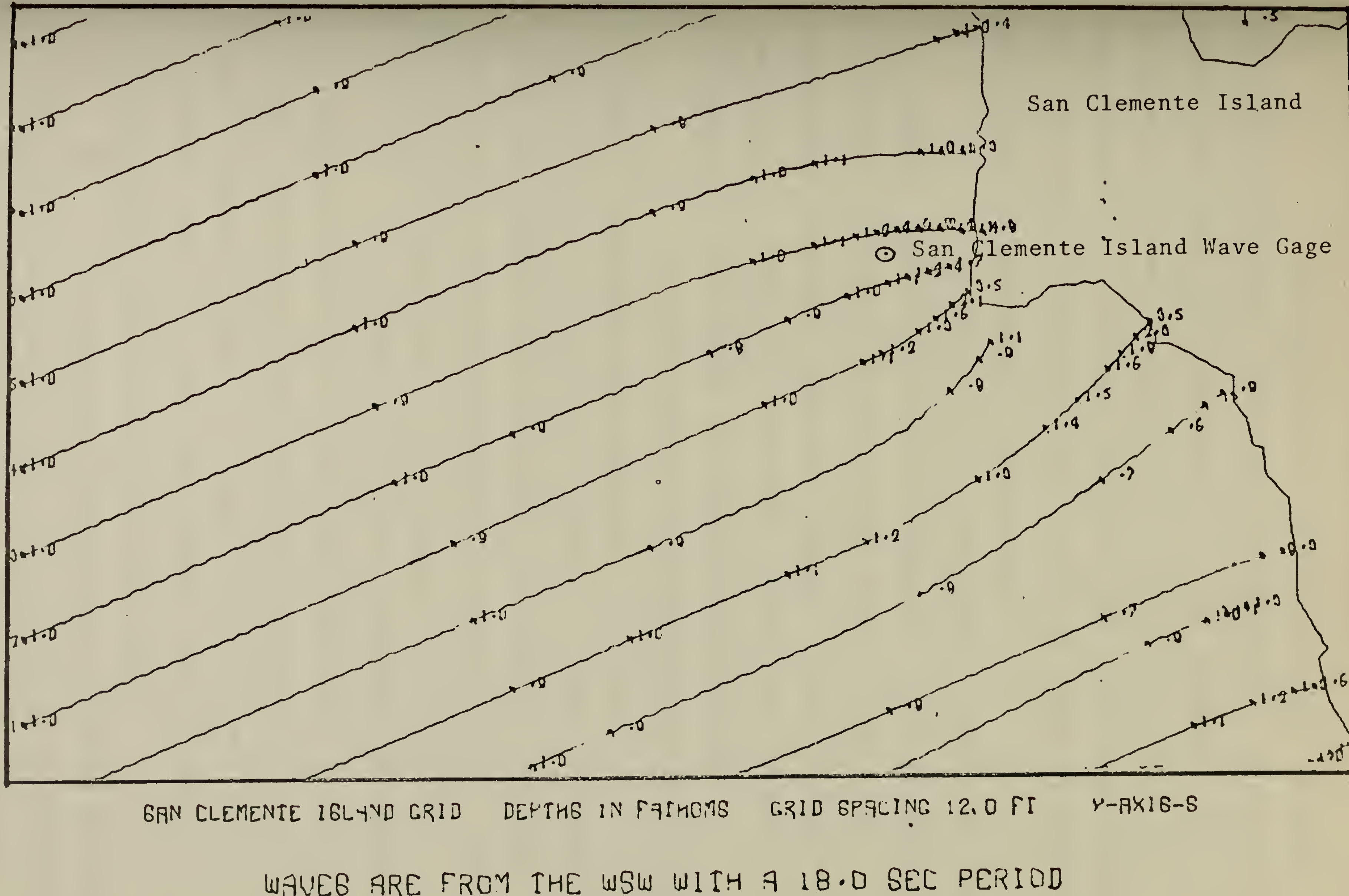

Figure 12: Example of wave refraction diagram.

An example of a refraction diagram printout is shown in Figure 12. The shoreline boundary is drawn from grid-point values that were input into the program. The program also draws the paths of the wave orthogonals from deep water to the shoreline and prints out along each orthogonal the wave-height coefficient (H/H_o) which is calculated using the refraction and shoaling coefficients.

Although the program computes refraction factors at irregular intervals along the orthogonals, it was decided to manually calculate the refraction factor at the wave sensor site from each refraction diagram. This was done by measuring the orthogonal separation in deep water and at the sensor site and using the equation stated above.

On those refraction diagrams where more than one pair of orthogonals bracketed the wave sensor site due to the crossing of orthogonals to seaward, a single refraction factor was obtained for the sensor site from the root-mean-square of the two or more measured refraction factors. The refraction factors computed are tabulated in Appendix A.

The refraction factors obtained were plotted on a graph of wave period versus deep-water wave direction to produce a refraction graph for the wave sensor site. This graph is shown in Figure 13. Using the FNWC wave direction and period data, the refraction factors to be applied to the FNWC heights were obtained from this graph.

No refraction diagrams were prepared for the shoal-water areas lying distant from and largely surrounding San Clemente Island because of the enormous task involved.

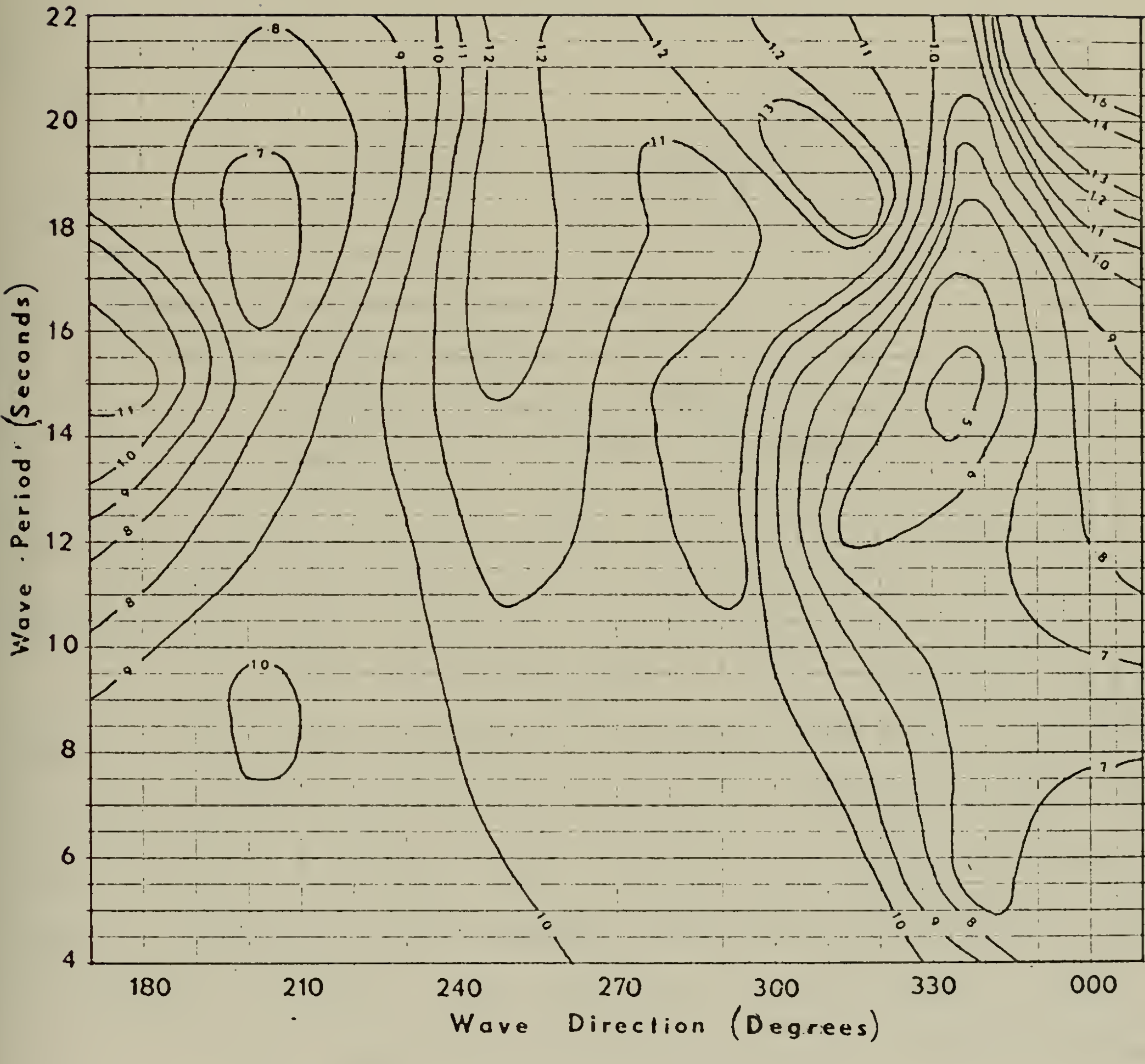

Figure 13: Refraction factors at the sensor site.

(2) Shoaling Factor. The shoaling factor represents the change of wave height due to alteration of the orbital water-particle motions as waves transit a shoaling bottom. According to linear wave theory the shoaling factor, K_s, is given by:

$$K_s = \left(\frac{V_o}{V}\right)^{1/2} = \left(\frac{1}{2n \; C/C_o}\right)^{1/2}$$

where: V = wave group velocity
C = wave speed
n = ratio of group velocity to wave speed
subscript "o" denotes deep water.

The shoaling factor can be shown to be a function of wave period and the water depth at the wave gage site.

The shoaling factor at the sensor site (water depth 40 feet) for the range of periods from 0 to 25 seconds was obtained through the use of Wiegel's Tables [Wiegel, 1954] and is plotted in Figure 14. The shoaling factor was obtained from the graph for each analyzed FNWC period for use in correcting the FNWC wave heights from deep water to the sensor site.

(3) Hydrodynamic Damping Factor. The hydrodynamic damping factor, or pressure response factor, accounts for the decrease in apparent wave height as measured by the wave sensor on the sea floor and not at the surface. The hydrodynamic damping factor, K_d, is given by:

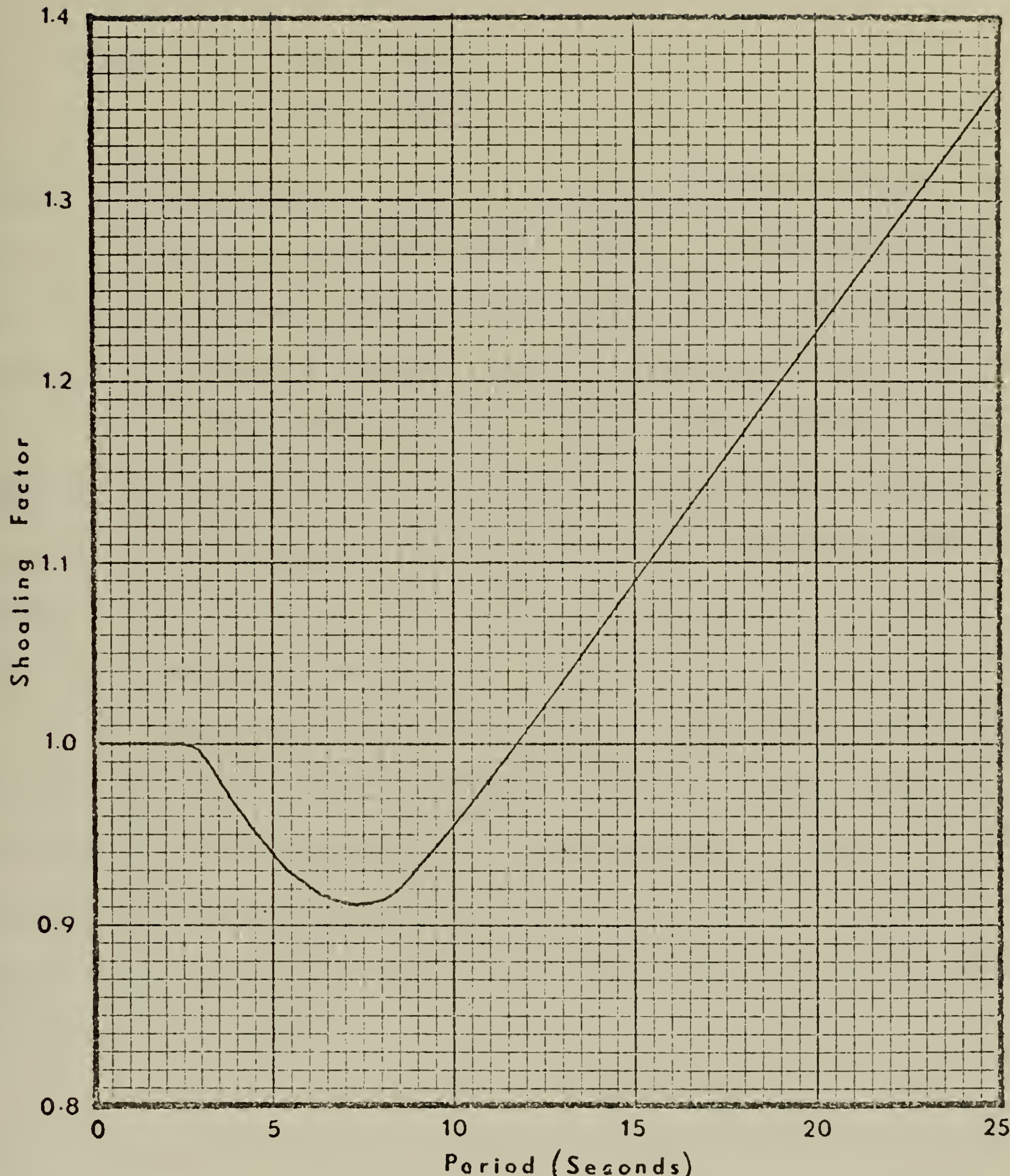

Figure 14: Shoaling.Factors at the sensor site.

$$K_d = \frac{1}{\cosh 2\pi d/L}$$

where: d = water depth
L = wave length.

Like the shoaling factor, the hydrodynamic damping factor is a function of wave period and water depth. The value of K_d at the sensor site was obtained for wave periods of 0 to 25 seconds using Wiegel's Tables and is plotted in Figure 15.

The FNWC analyzed heights were reduced from surface to bottom values by use of the hydrodynamic damping factors from this graph obtained using the associated FNWC periods.

b. Period Corrections

Shoal-water processes have a negligible effect on the peak period in a swell spectrum because of the characteristically narrow bandwidth of the spectrum. Swell periods were therefore considered to be conserved, and those swell periods recorded at the sensor site were taken to be the same as those in deep water.

However, shoal-water transformations may cause a shift of the period peak in a wind-wave spectrum because the range of periods having significant energy is much broader. The effect of these processes was investigated and the results are presented in Appendix B. It was found that when the correction factors were applied to fully arisen seas generated by wind speeds of less than 40 knots from the northwest, west,

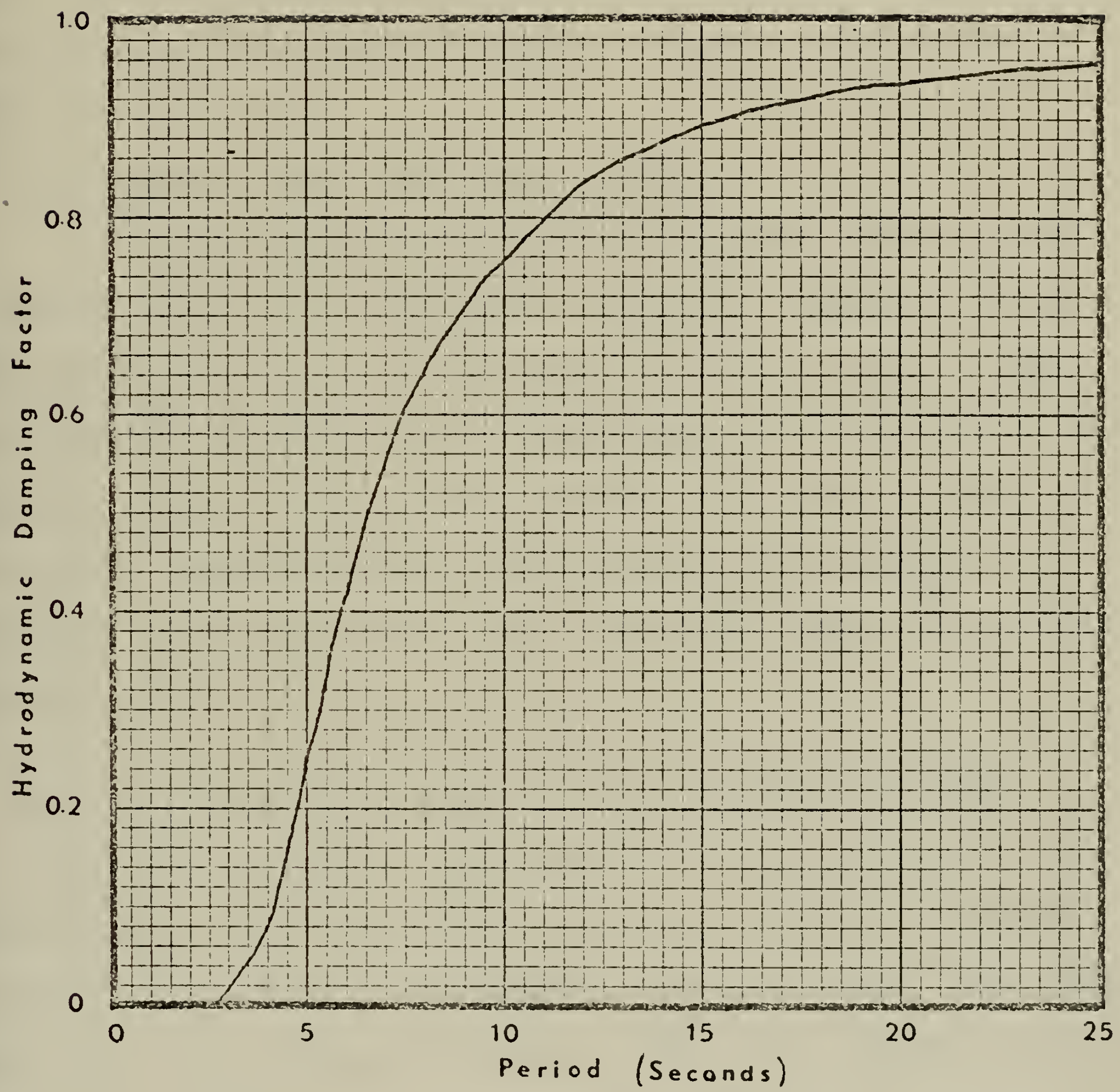

Figure 15: Hydrodynamic damping factors at the sensor site.

and southwest, the shift in peak period was less than one second. From these results it was concluded that a period shift of up to one second can be expected to occur in wind waves due to shoaling processes. Thus, a one-second variation in the period verification should be expected due to the effects of shoaling.

2. Combining the FNWC Wave Heights

A second modification was made to the FNWC heights. As stated previously, and as may be seen in Figure 11, the FNWC output gives both a wind-wave and swell height. The recorded wave heights, on the other hand, are composed of the combined heights of all waves present. In order to make a suitable comparison, the FNWC heights were combined by a root-mean-square procedure after the shoal-water corrections were applied.

D. POSSIBLE SOURCES OF ERROR IN THE FNWC WAVE ANALYSES

There are basically three possible sources of error in the FNWC analyses, other than those that might be inherent in the Sverdrup-Munk-Bretschneider forecast model, that could affect the final comparison of the FNWC data with the observed data. The first of these results from the fact that the FNWC analysis includes only the dominant swell train present, whereas there is frequently a second and possibly a third swell train present arriving from other generating areas. Accordingly, the wave energy in the swell present at a given location at a particular time could be somewhat greater than that predicted by FNWC. Assuming that the total significant height of all

swell trains present can be represented by a root-mean-square value of the individual heights of each swell train, and assuming that all swell heights are equal, the maximum error of the resultant swell height above the dominant swell height predicted by FNWC will be 29.3% for a second swell train present and 42.3% for a third swell train present. This condition is the extreme and will occur infrequently.

If the second and third swell trains have heights less than that of the dominant swell train, the error in prediction of swell heights will be less than 29.3% and 42.3%, respectively. Figure 16 shows the error in swell height given by FNWC for various heights of a secondary swell train, if present. The errors created by the presence of a third swell train may be treated in a similar manner.

The second possible source of error results from the difference in location between the FNWC coastal boundary, for the 63 x 63 Northern Hemisphere grid, and the actual coastal boundary. This causes waves to be generated by the model which are not possible due to fetch limitations along the coast. The FNWC analysis program checks by use of a Land-Sea Table (developed by FNWC) to determine whether or not propagating swell reaches land at each grid point. When land is reached, the swell train is terminated. The Land-Sea Tables denote the coastal boundaries fairly accurately, but do not take into account the presence of the Southern California islands as limitations to wave generation or swell propagation unless the grid point

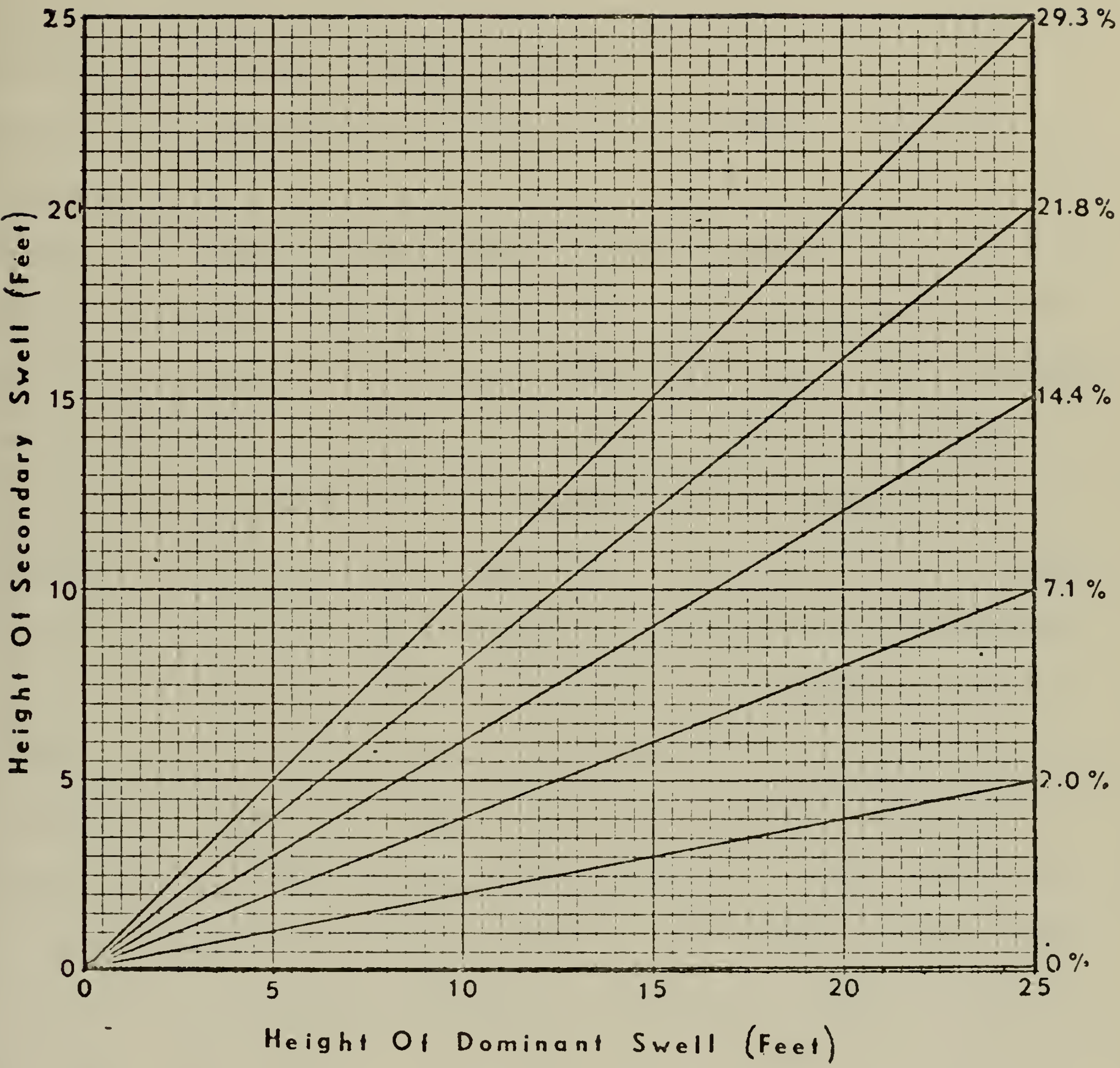

Figure 16: Error for a second swell train present.

happens to fall on the island. Swell arriving from directions between south-southeast and north-northwest are not affected because the selected grid point is in a deep-water location with respect to local coastal boundaries. However, to the north and east, there are islands located between the grid and the coast.

Figure 17 shows the distance to the nearest land, i.e., the fetch available for wave generation for the selected grid point (I-20, J-18). If all the islands are taken into account, the fetch available for wave generation from most northerly and easterly wind directions is less than what FNWC uses. To determine whether or not FNWC waves reported from northerly and easterly directions are possible, the following procedure was used. If the wave direction given in the FNWC analysis was from a landward direction, the fetch for that direction was read from Figure 17. The wind speed for the area was obtained from the FNWC surface wind analysis, and a check was made using Anderson's Curves [Anderson, no date] to determine if the waves predicted by FNWC have occurred. When it was found that the predicted wave conditions could not have been generated, then these FNWC heights and periods were not included in the verification. It was recognized that wind speeds greater than those analyzed by FNWC could have occurred, and that these greater wind speeds could have generated wind conditions

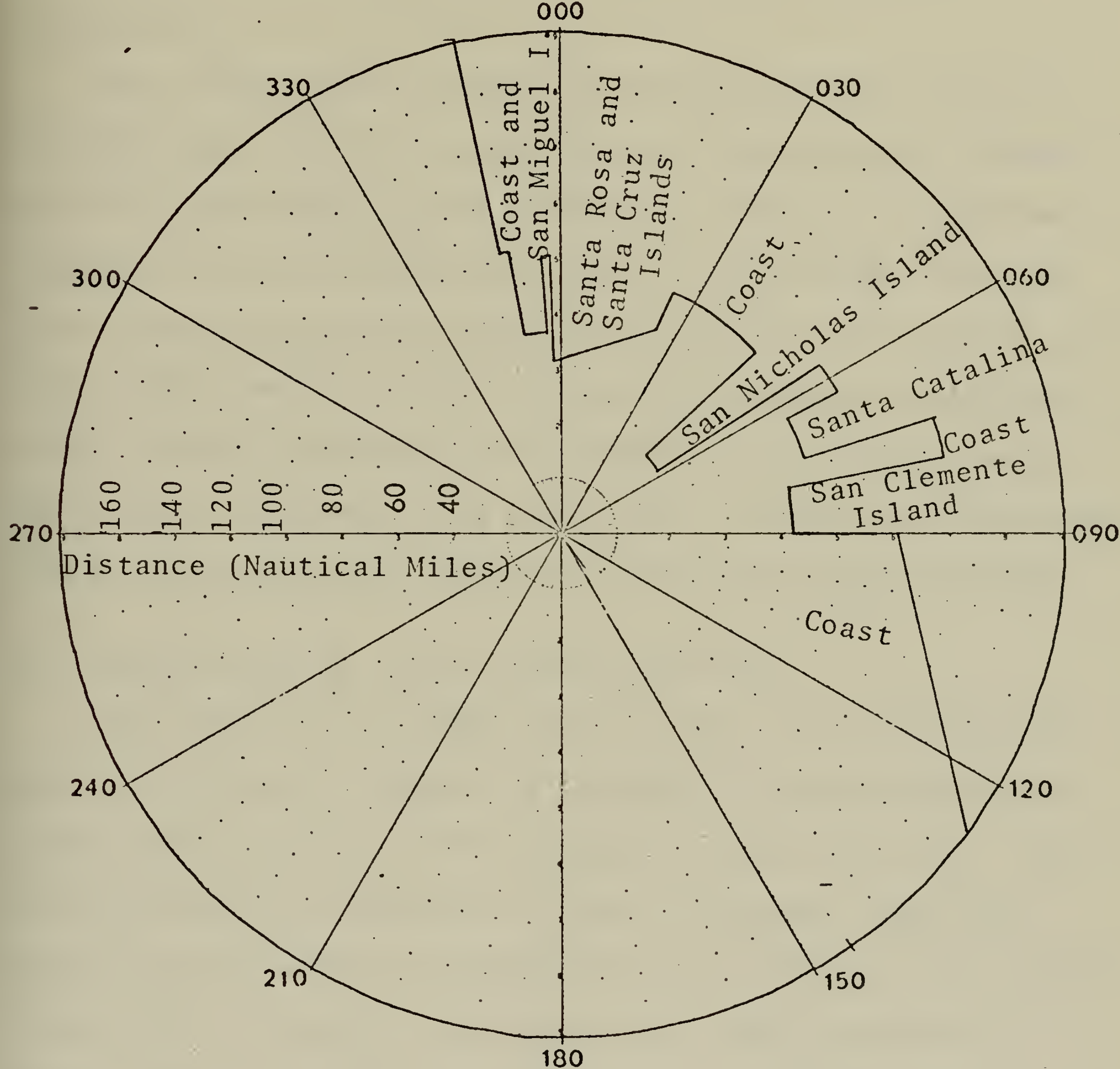

Figure 17: Distance to nearest land from the grid point.

exceeding those given in the analysis; accordingly, a 10% leeway in the wave height and period possible was allowed in determining whether the FNWC wave conditions were reasonable.

The third possible source of error in verification of the FNWC wave analyses is due to the large distance between the FNWC grid points (grid spacing) on the 63 x 63 Northern Hemisphere grid (230 nautical miles at 30° North Latitude). This large grid spacing causes the analysis, on occasion, to miss local, small-scale wind fields off Southern California such as Santa Ana winds or the onshore coastal sea breezes that affect the local wave conditions. Local wave conditions can be expected to be recorded by the wave sensor, however.

E. PRESENTATION OF THE FNWC WAVE ANALYSES

The results of the FNWC analyses for the selected grid point are shown in Figures 18 through 21 for the period of study from October 21, 1971 through December 31, 1971. The wave periods were converted to wave frequency, and these values, along with the significant wave heights, are plotted versus time in hours. The values are shown for every 12 hours, 0000Z and 1200Z, corresponding to the times of the FNWC wave analyses. Both wind wave and swell frequencies are plotted in the figures; the dominant waves present are shown by squares. The significant height values plotted are the root-mean-square combined heights of the wind waves and the dominant swell, corrected to the sensor location. By noting

which height was the greater, wind wave or swell, it could be determined whether the swell or the wind waves were dominant. The height and frequency values are plotted on the same time scale so that time changes in the height and frequency can be oberved together as an aid to identification of synoptic wind wave and swell trains generated in individual wind areas.

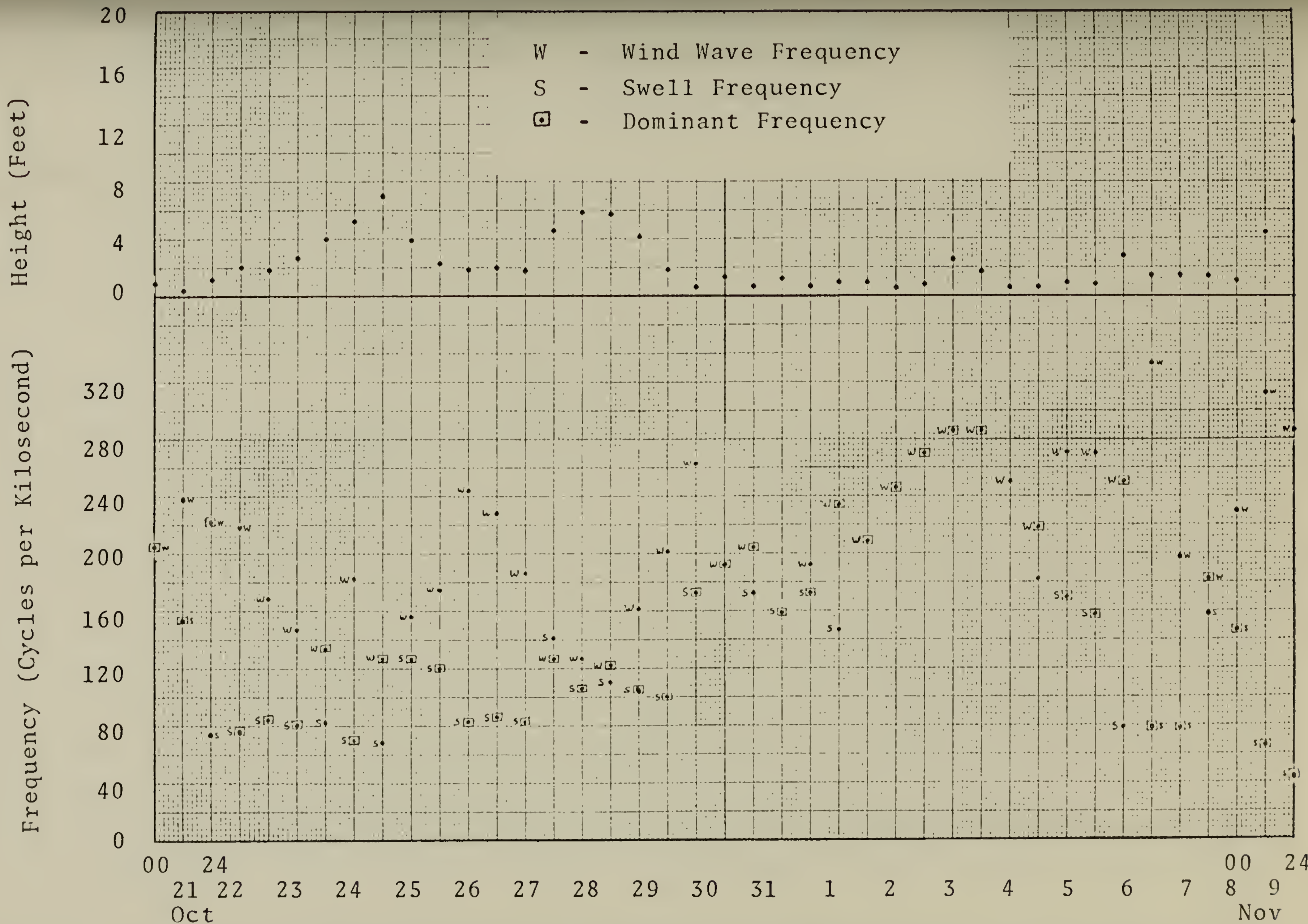

Fig 18: FNWC Wave analyses (heights are combined after corrections applied).

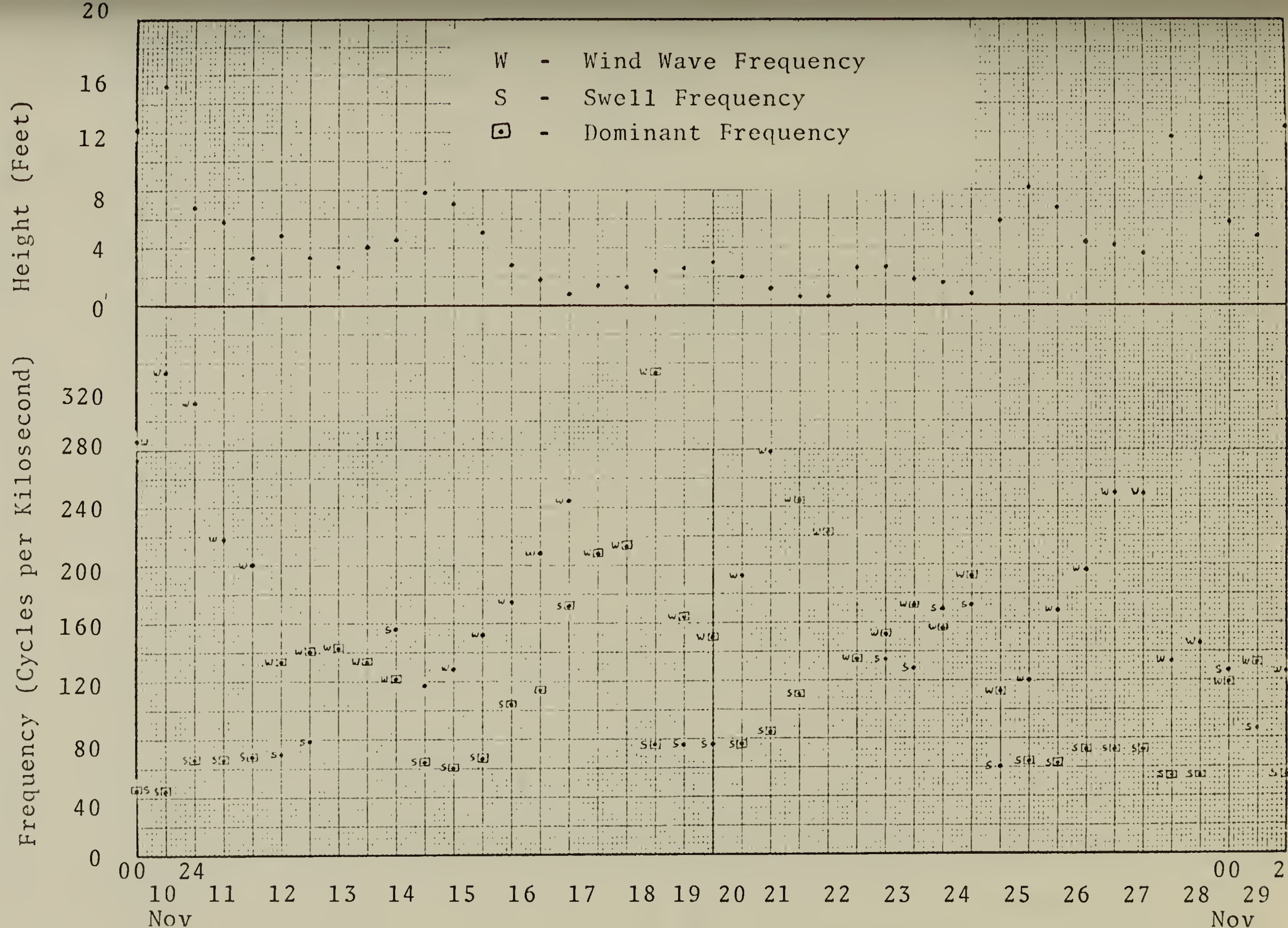

Figure 19: FNWC wave analyses (heights are combined after corrections applied).

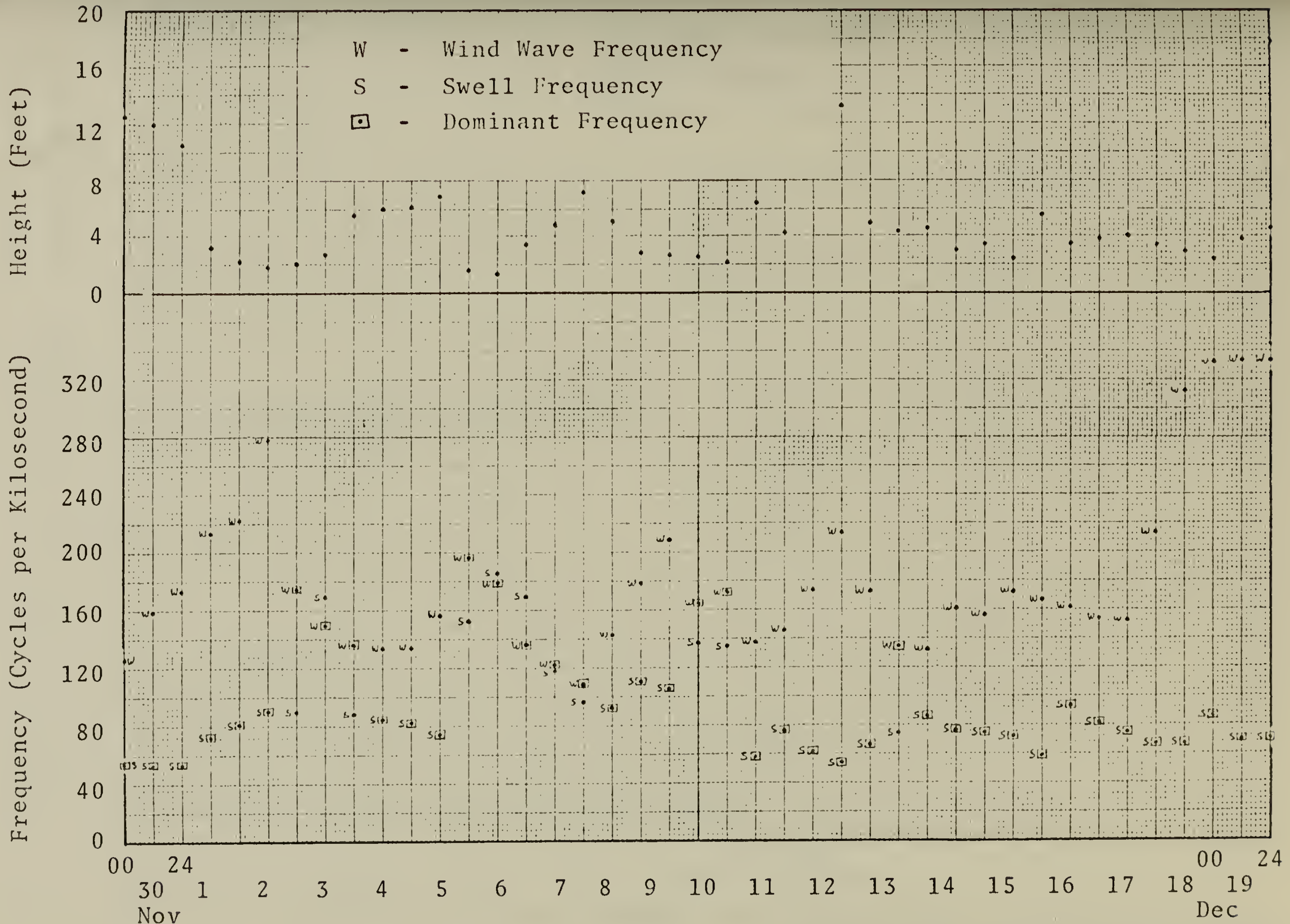

Figure 20: FNWC wave analyses (heights are combined after corrections applied).

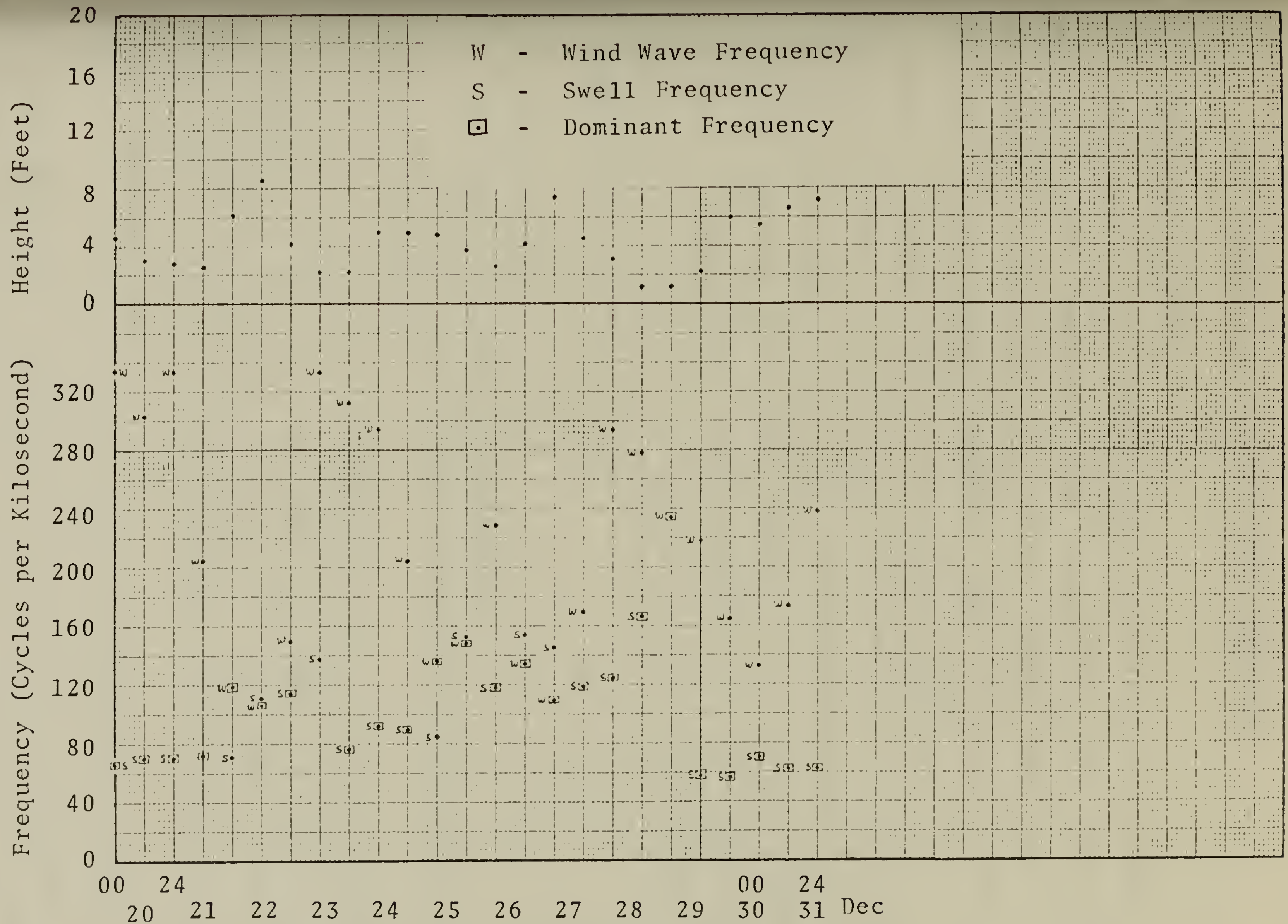

Figure 21: FNWC wave analyses (heights are combined after corrections applied).

V. VERIFICATION OF FNWC WAVE ANALYSES

A. VERIFICATION METHOD

The procedure followed for the verification of the FNWC wave analyses by comparison with recorded wave data from the San Clemente Island wave sensor was to compare the two sets of wave data for the same analysis times. The verification of wave periods and heights was done separately and in a different manner. The FNWC wind wave and swell periods were verified by comparing them with the dominant periods obtained from the analysis of the wave records. The resultant heights derived by the root-mean-square combination of the FNWC wind wave and swell heights were compared with the wave heights obtained from the wave records.

B. FNWC WAVE DATA NOT USED

1. Basic Problems in Verification

a. Grid Point Location Different from Wave Sensor Location

As was stated previously, and as can be seen in Figure 1, the grid point for which the FNWC wave analyses to be verified were made is located 79 miles west of the wave-gage site. This fact caused problems in verifying wind waves from all directions.

The basic problem in the verification of wind waves is that the fetch involved in wave generation at the two locations is different for most directions considered. The FNWC

wave analyses for the two-month period of this study showed wind waves from practically all directions. Therefore, the waves generated should not be the same at both the grid point and wave sensor site in those cases where the sea is fetch limited at one or both locations. If the waves have become fully arisen prior to arrival at the two sites, then the waves computed for the grid point can be considered to be the same in deep water at the sensor site, and can be used for verification after shoaling modifications are applied. Whether or not the sea was fully arisen at both sites was determined by use of the appropriate fetch and the surface wind obtained from the FNWC wind analysis, assuming the wind to blow uniformly from the coast to the offshore sites. If fully arisen, the FNWC wind waves were used in verification.

If the waves proved to be fetch limited at one or both sites, however, the sea conditions were considered to be indeterminate and no verification was made. The wind waves from seaward directions of 153° to 348° were not used in the verification because the fetch to the two sites in question was in all cases different. It was beyond the province of this study to determine, for those wind waves, if the waves were fully arisen or not.

b. Shoal Water Areas to Seaward of Sensor Site

As can be seen in Figures 1 and 2, the San Clemente Island wave sensor site is largely encircled by shoal-water areas to seaward that affect long-period waves. Swell from

directions 153° to 010° are refracted over these areas prior to arrival in deep-water at the sensor site (Figure 2). However, they are unaffected upon arrival at the selected FNWC grid point. As stated previously, refraction diagrams were not prepared for the seaward shoal areas because of the considerable number of diagrams that would be involved. Therefore, those FNWC swell periods that fall inside the curve of Figure 2 were verified for both period and height; the swell periods that fall outside the curve were verified for period only, the swell heights being indeterminate in the absence of refraction information. Swell periods can be verified in either case because they are conserved during shoaling as discussed earlier.

2. <u>Summary of FNWC Wave Data Not Used for Verification</u>

The following FNWC wave data were not used for verification for the reasons listed:

(1) FNWC wind waves having periods that could not have been generated over fetches limited by local coastal boundaries were not used.

(2) All wind waves and swell from directions 010° to 153° were not used because there were no recorded data with which to verify the FNWC waves; the wave sensor site is almost totally sheltered from these directions by San Clemente Island.

(3) Wind waves from directions 153° to 348° were not used at all for the reasons stated in the previous section.

(4) The swell heights from 153° to 010° were not used if the associated swell were affected by shoaling and refraction in shoal areas to seaward of the sensor site.

(5) Wind waves from directions 348° to 010° were not used unless the seas were determined to be fully arisen because the fetches are different at the two sites and the sea conditions accordingly should not be the same.

(6) FNWC periods of less than five seconds which are primarily wind waves were not used because the wave sensor will not record these short periods due to hydrodynamic damping.

(7) FNWC wave data for those times when no recorded wave data were available could not be used.

C. PRESENTATION OF THE WAVE DATA TO BE VERIFIED

After discarding the FNWC wave data that could not be used for verification the wave data that were used include:

(1) All swell periods from directions between 153° and 010° were used.

(2) Those swell heights from directions between 153° and 010° associated with periods that were not affected by shoaling and refraction in shoal areas to seaward of the sensor site were used.

(3) Those wind waves from directions between 348° and 010° that had reached a fully arisen state were used.

The recorded wave heights were plotted along with the combined FNWC heights for corresponding times and are presented

in Figures 22 and 23. The dominant wave frequency from each San Clemente Island wave record was plotted along with both the FNWC wind wave and swell frequencies for corresponding times. These frequency plots are shown in Figures 26 through 30.

D. RESULTS OF THE VERIFICATION

1. Results of Height Verification

The degree of comparison found between the computed and the recorded combined wave heights can be observed from a time series standpoint in Figures 22 and 23. The time scale in the figures is not continuous due to missing or unverifiable data and the breaks in the time scale are noted. The results of the verification are summarized in Figures 24 and 25, which are derived from the above figures. In Figure 24, the FNWC combined heights are plotted versus the recorded heights. The lines on the graph denote the amount in feet by which the FNWC heights (H_F) deviate from the recorded heights (H_R). $H_F - H_R = 0$ indicates a perfect comparison, whereas positive values indicate an overprediction and negative values an underprediction of the FNWC heights with respect to the recorded heights. The information contained in Figure 24 is further summarized in Figure 25 in the form of a histogram and cumulative curve showing deviation of the FNWC periods from the recorded periods. Because of the limitations placed on the use of FNWC wave height data discussed previously, only 24 height comparisons could be made.

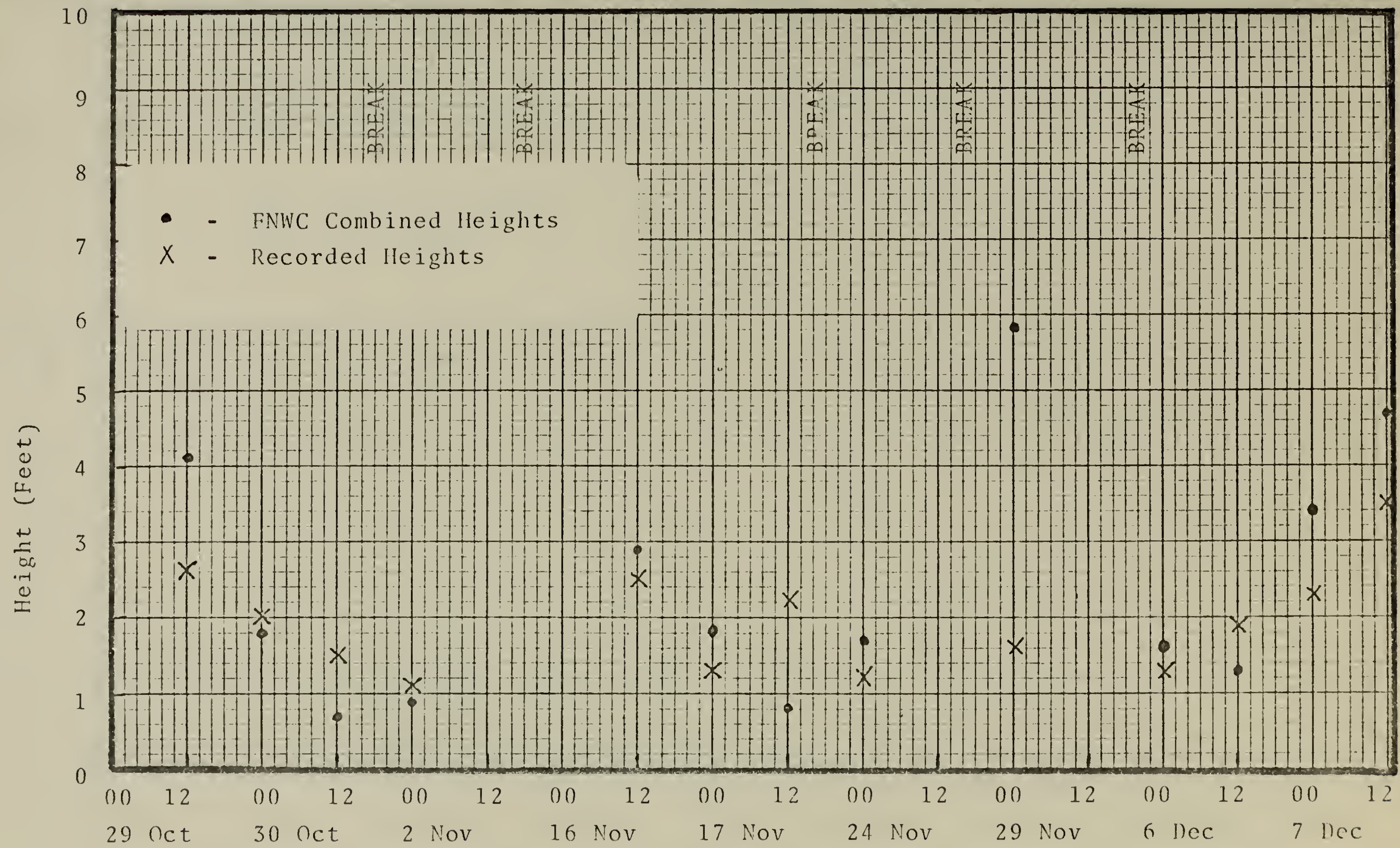

Figure 22: Height comparison time series.

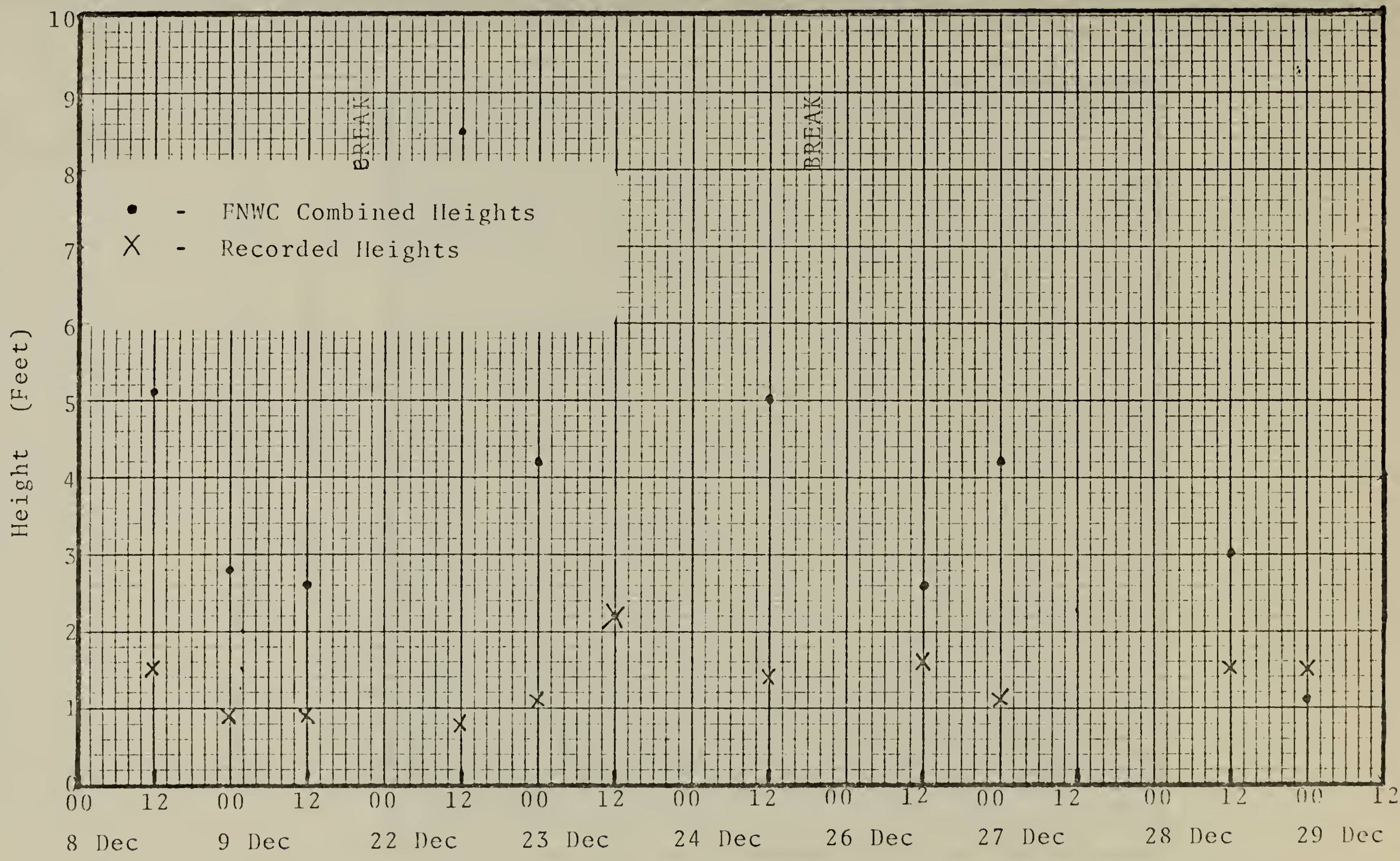

Figure 23: Height comparison time series.

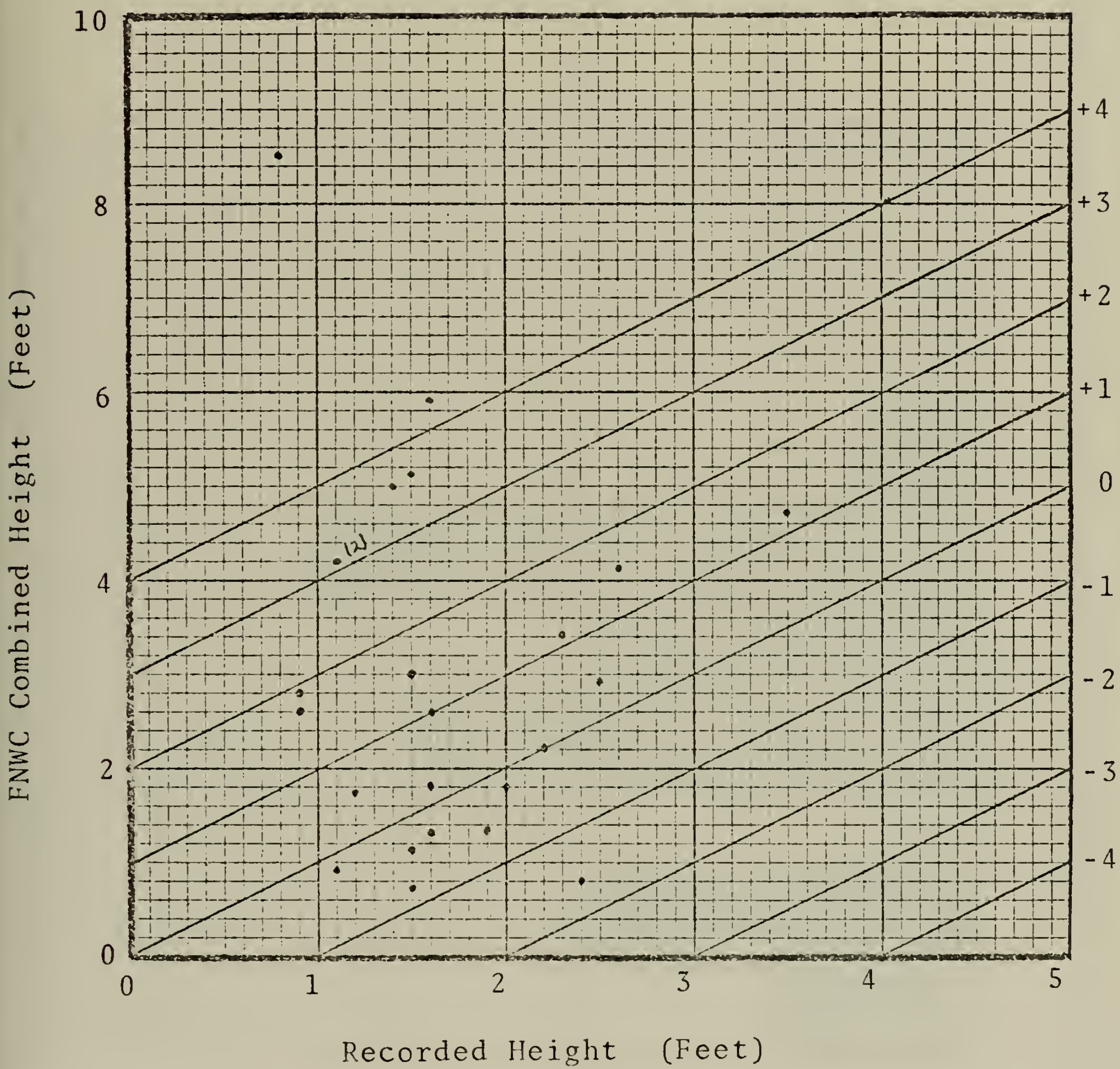

Figure 24: Scatter diagram of heights compared.

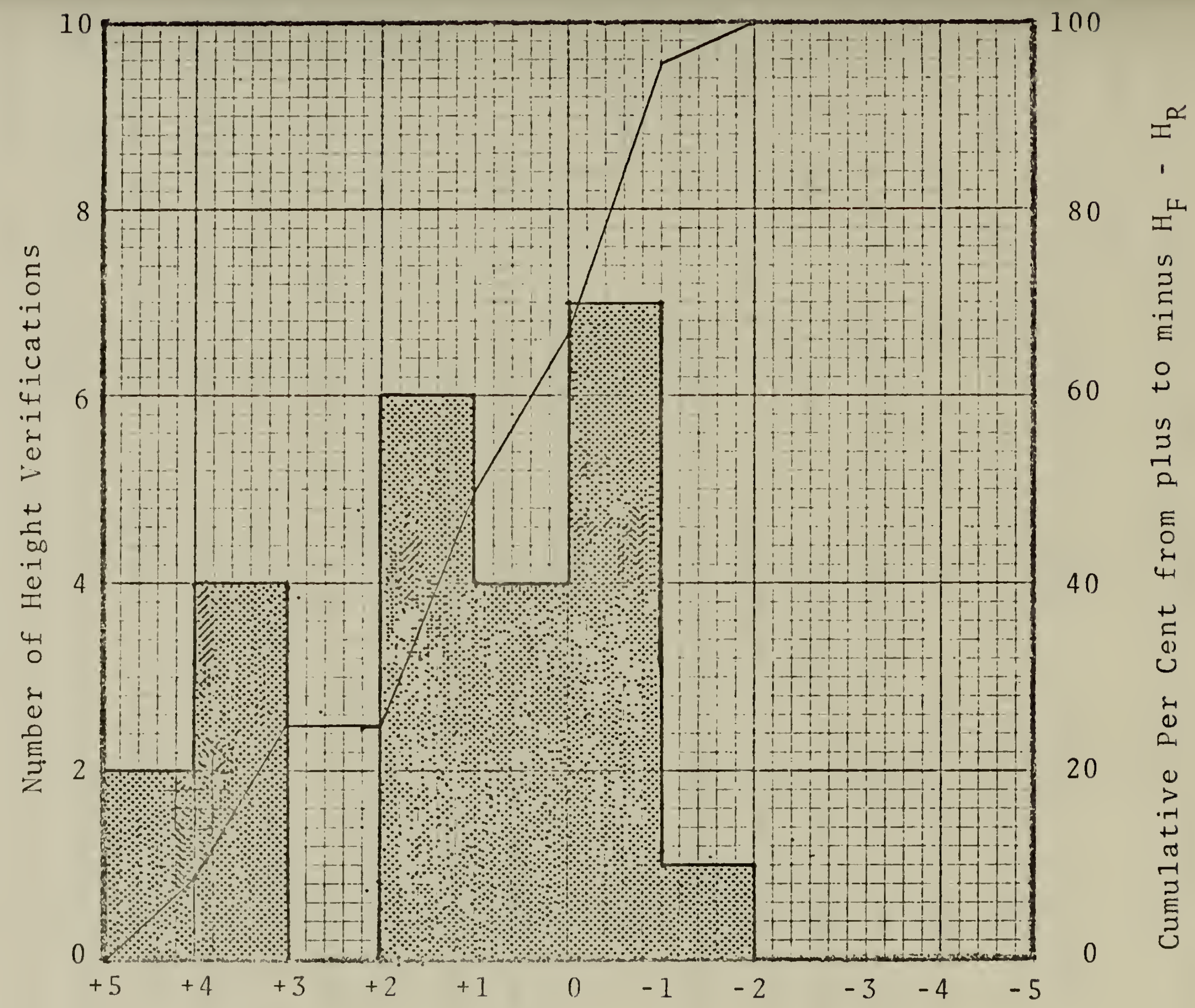

Figure 25: Histogram and cumulative per cent of heights compared.

The following conclusions can be drawn from Figures 24 and 25:

(1) The recorded heights ranged between 0.8 and 3.5 feet, whereas the FNWC combined heights ranged between 0.7 and 8.5 feet.

(2) Of the 24 comparisons made, 11 (46%) of the FNWC heights fell within ± 1 foot of the recorded heights, 18 (75%) fell within ± 2 feet, and 22 (92%) fell within ± 4 feet.

(3) The median deviation between the FNWC and recorded waves was +1.0 feet, as is indicated by the cumulative curve of Figure 25; this indicates a tendency toward over-prediction of the wave heights by the FNWC wave analysis scheme.

2. Results of Period Verification

The degree of comparison found between the computed and the recorded wave periods in the form of wave frequency can be observed from a time-series standpoint in Figures 26 through 30. The time scale in the figures is not continuous due to missing or unverifiable data. The results of the verification are summarized in Figures 31 and 32, which are derived from the above figures. In Figure 31 the FNWC periods for both swell and wind waves are plotted versus the dominant recorded period. The family of lines on the graph denote the number of seconds by which the FNWC periods (T_F) deviate from the recorded periods (T_R). $T_F - T_R = 0$ indicates a perfect comparison, whereas positive values indicate an overprediction and negative values indicate an underprediction of the FNWC

periods with respect to the recorded periods. The information contained in Figure 31 is further summarized in Figure 32 in the form of a histogram and cumulative curve showing deviation of the FNWC periods from the recorded periods.

Examination of Figures 31 and 32 show that:

(1) The range of recorded periods was from 6.4 to 18.3 seconds, whereas the FNWC periods ranged from 4.7 to 18.9 seconds.

(2) The difference between the FNWC periods and the recorded periods (i.e., $T_F - T_R$) ranged from +11.2 to -9.0 seconds. However, when the two groups of periods marked A and B on Figure 31 are discarded, the difference range is +4.0 to -9.0 seconds; it is probable that these groups represent long-period swell predicted by FNWC, whereas the wave gage recorded only short-period waves.

(3) Of the 88 period comparisons made, 23 (26%) of the FNWC periods fell within ± 1 second of the recorded periods, 40 (45%) were within ± 2 seconds, 58 (66%) were within ± 4 seconds, and 79 (90%) were within ± 6 seconds.

(4) The FNWC periods, when both swell and wind waves are considered, tend to be underpredicted as indicated by the fact that 52 of the 88 comparisons (59%) are negative. This is best seen in Figure 32.

(5) When swell only is considered, 36 of the 74 comparisons (49%) are positive and the remainder (51%) are negative, indicating no tendency for FNWC to overpredict or under-predict the swell periods.

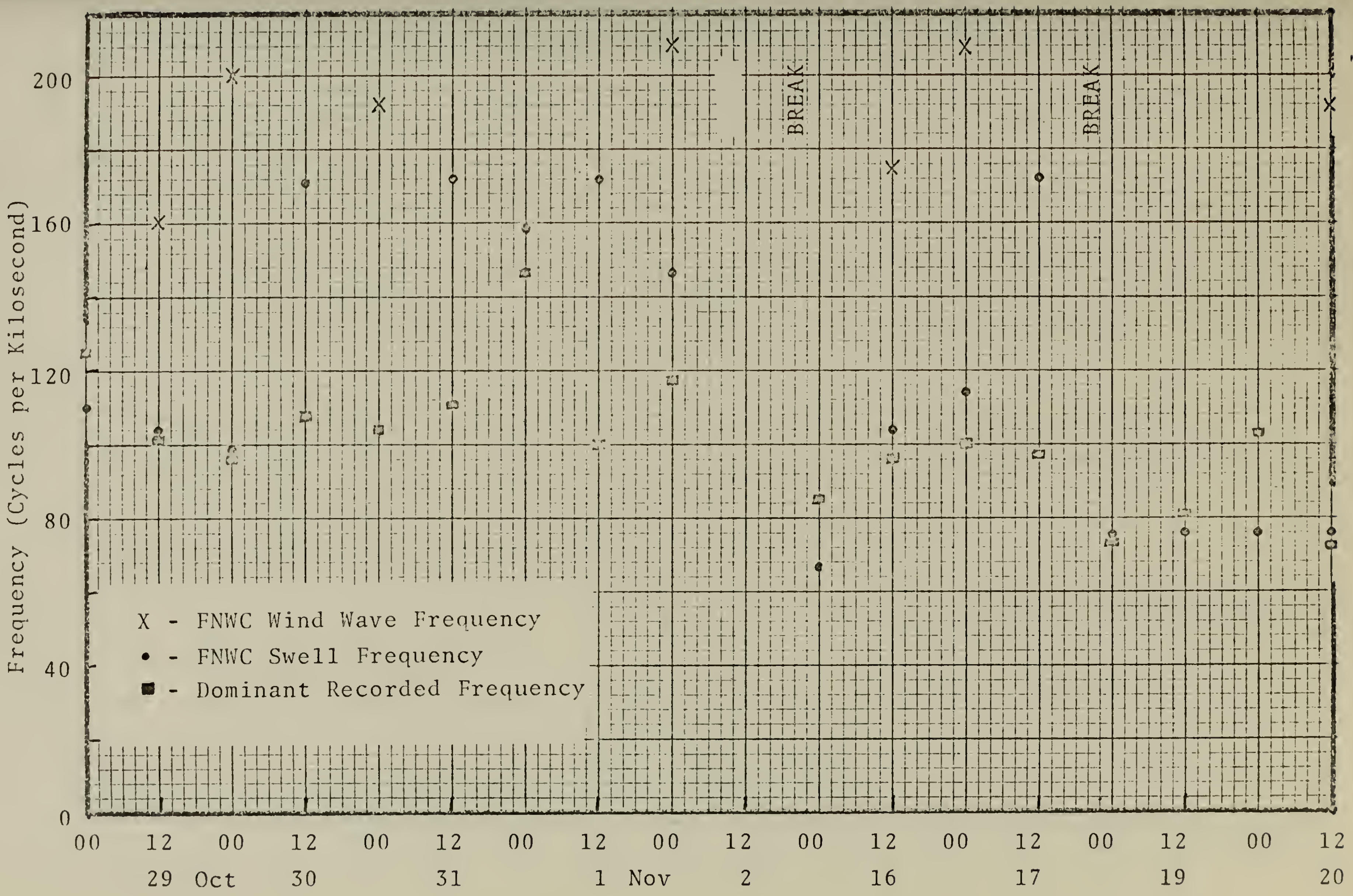

Figure 26: Frequency comparison time series.

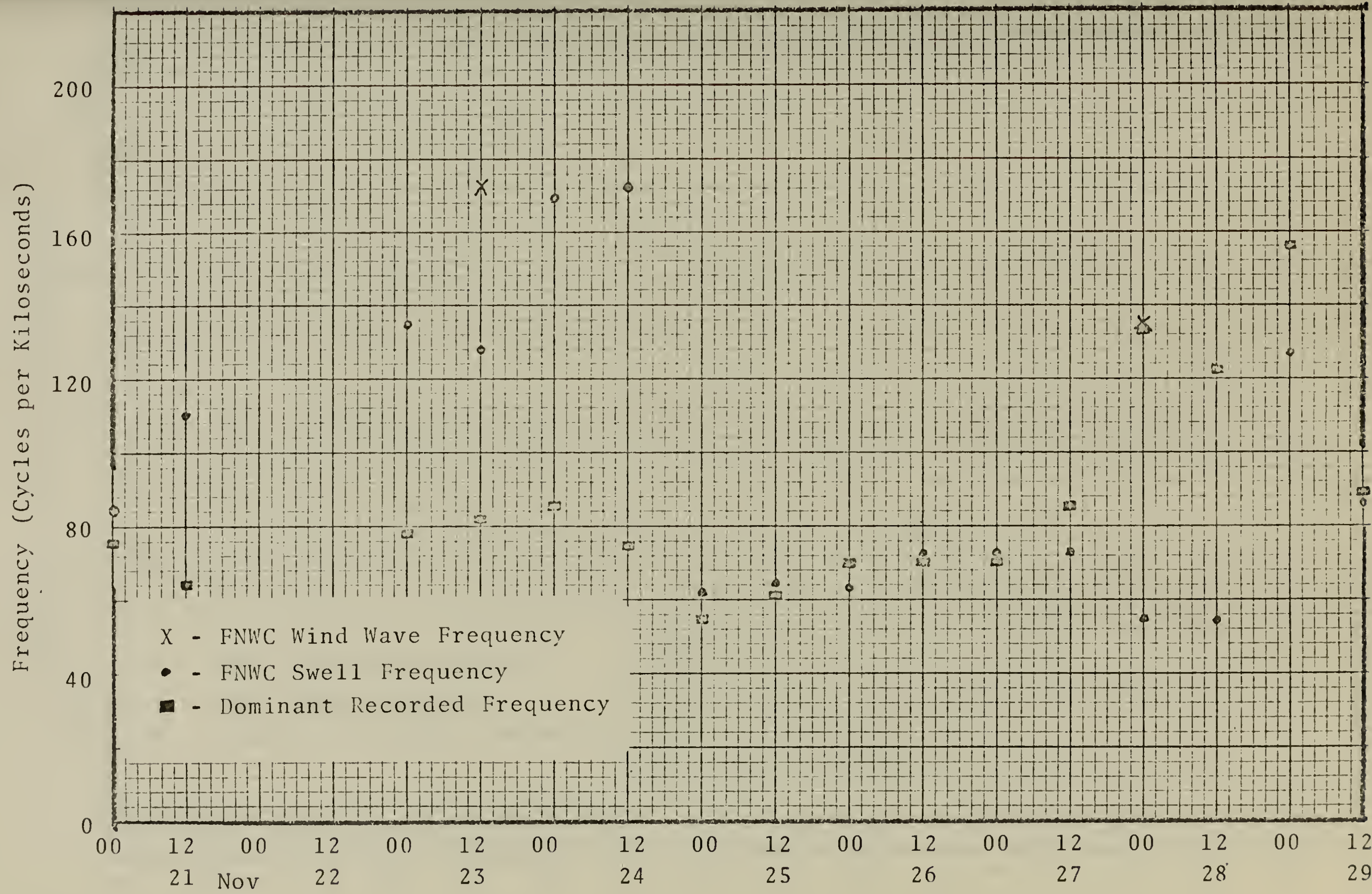

Figure 27: Frequency comparison time series.

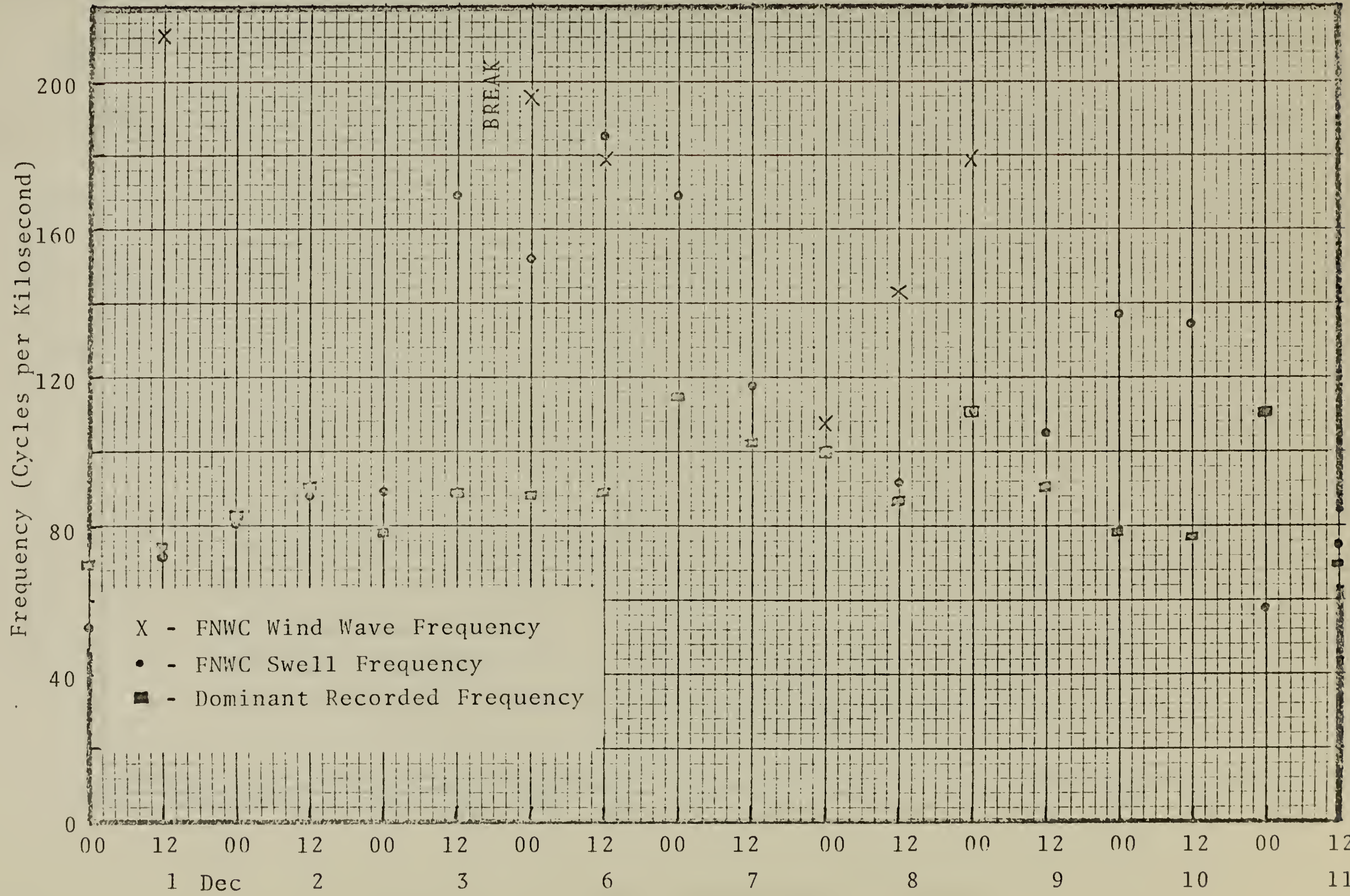

Figure 28: Frequency comparison time series.

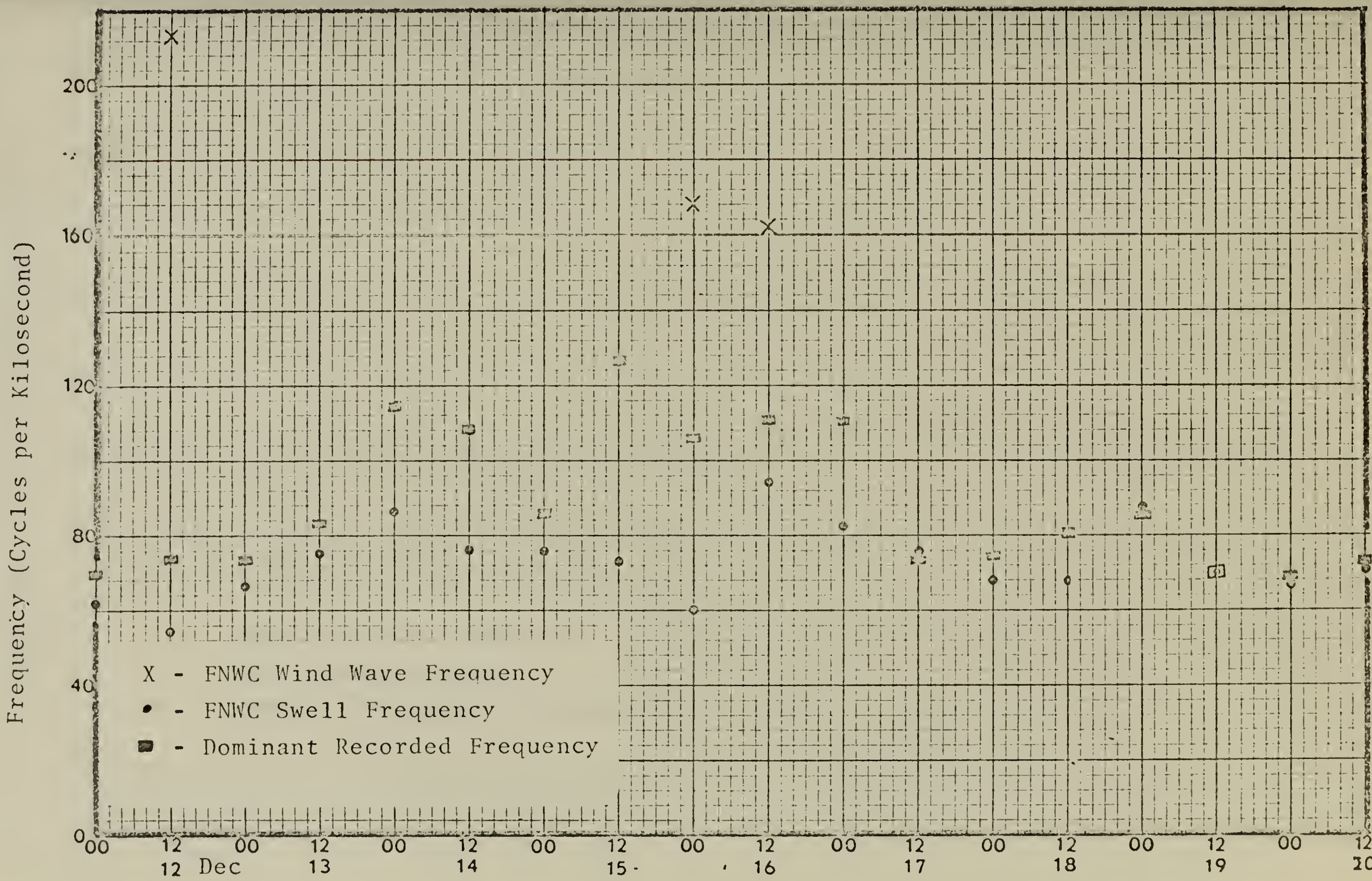

Figure 29: Frequency comparison time series.

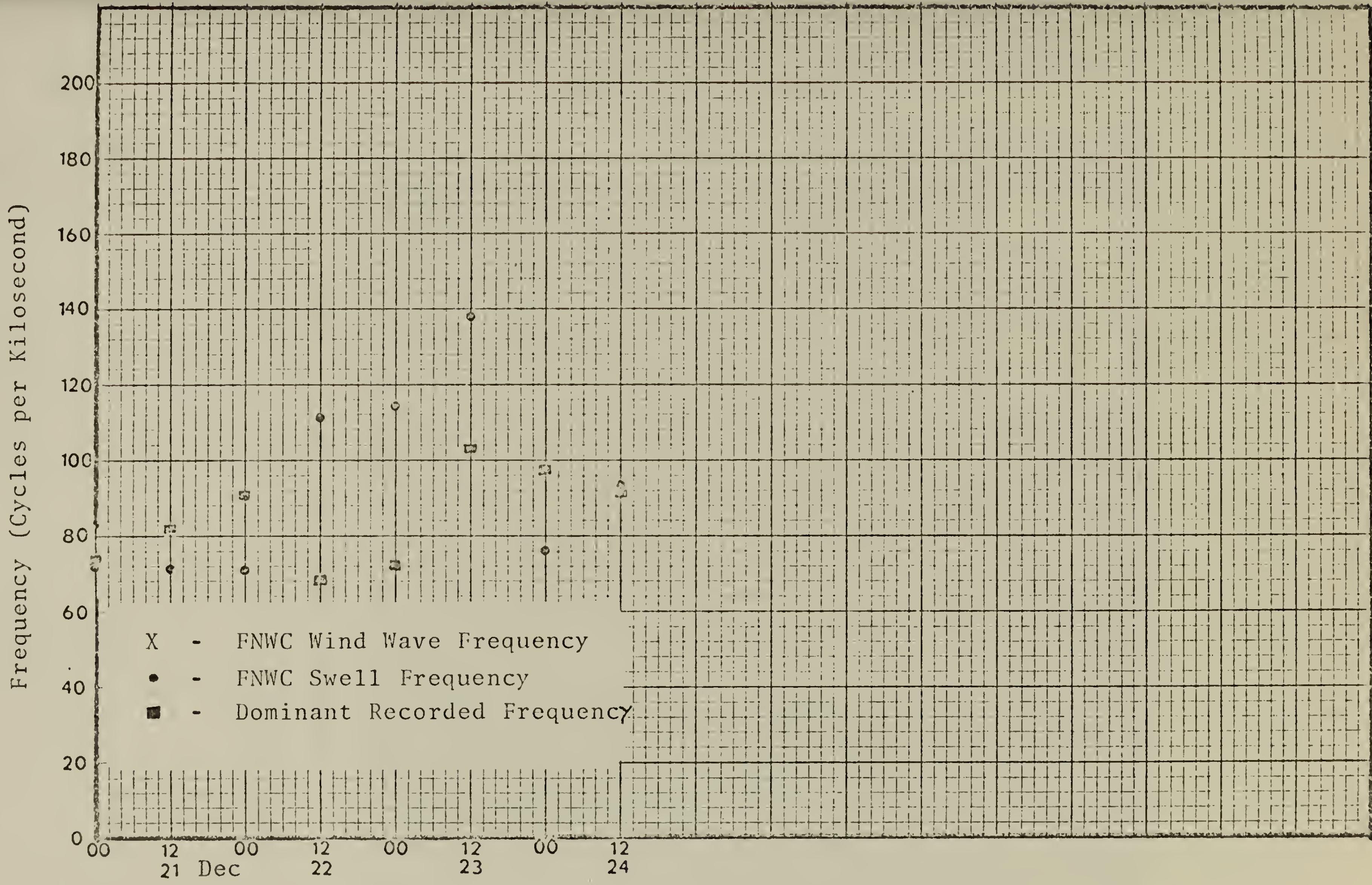

Figure 30: Frequency comparison time series.

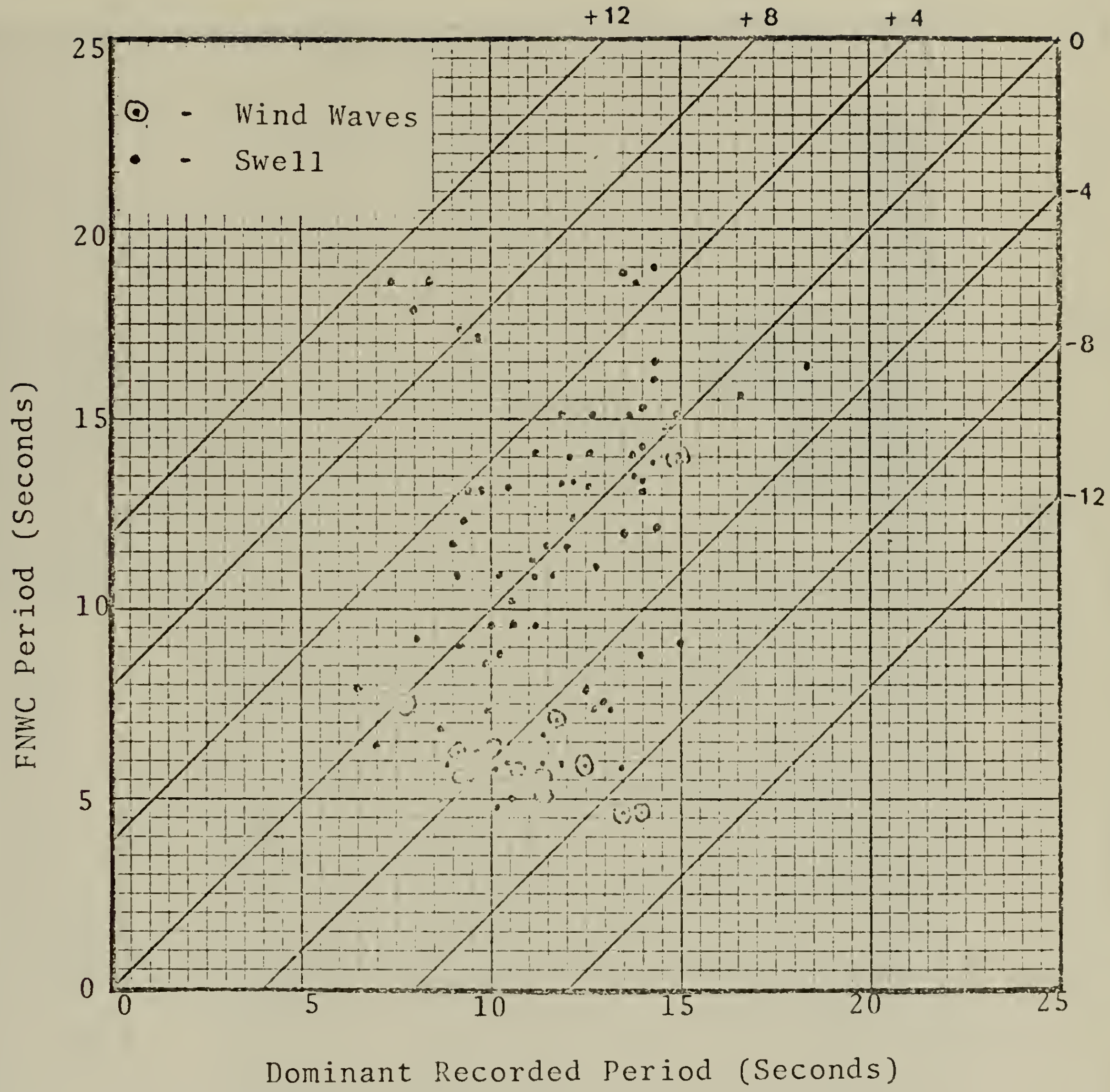

Figure 31: Scatter diagram of periods compared.

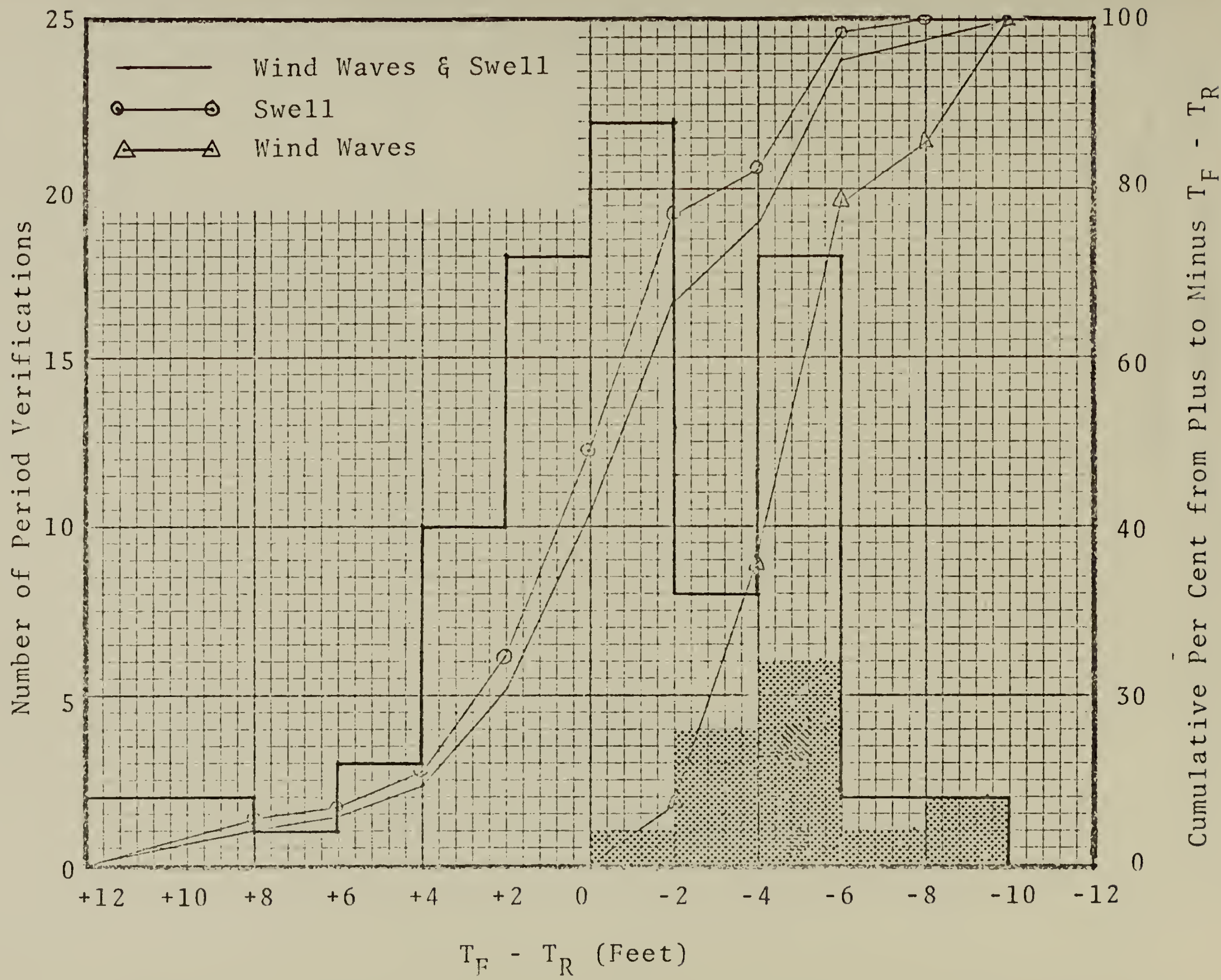

Figure 32: Histogram and cumulative per cent of periods compared. (Wind-wave periods are shaded)

(6) When wind waves only are considered, it can be seen that periods, which lie in the narrow range from 4.7 to 7.5 seconds, were underpredicted in all instances by an average amount of five seconds.

APPENDIX A: REFRACTION FACTORS FOR SAN CLEMENTE ISLAND WAVE GAGE

The following refraction factors (K_r) were computed using the computer program by Griswold (1963) for the various combinations of deep-water wave direction (ψ_o) and wave periods indicated.

Period 6 Seconds		Period 9 Seconds		Period 12 Seconds	
ψ_o	K_r	ψ_o	K_r	ψ_o	K_r
N	.748	N	.655	N	.798
NNW	.664	NNW	.666	NNW	.629
NW	1.000	NW	.891	NW	.580
WNW	1.000	WNW	1.070	WNW	1.120
W	1.010	W	1.036	W	1.070
WSW	1.000	WSW	1.040	WSW	1.142
SW	.964	SW	.944	SW	.955
SSW	.978	SSW	1.020	SSW	.886
S	.930	S	.915	S	.791

Period 15 Seconds		Period 18 Seconds		Period 21 Seconds	
ψ_o	K_r	ψ_o	K_r	ψ_o	K_r
N	.817	N	1.105	N	1.810
NNW	.480	NNW	.649	NNW	.959
NW	.726	NW	1.380	NW	1.105
WNW	1.145	WNW	1.050	WNW	1.270
W	1.080	W	1.128	W	1.150
WSW	1.208	WSW	1.274	WSW	1.225
SW	1.000	SW	.833	SW	.807
SSW	.744	SSW	.616	SSW	.786
S	1.155	S	.855	S	.863

APPENDIX B: SHIFT OF THE FREQUENCY OF MAXIMUM ENERGY IN A WIND-WAVE SPECTRUM DUE TO SHOALING

It was stated earlier in this paper that swell periods are conserved when passing through shoal water. This is because the swell spectrum is sufficiently narrow that shoaling processes will shift the peak frequency only a very small amount, if at all. That swell periods are conserved is a generally accepted fact.

However, it is not known what effect the application of refraction, shoaling, and hydrodynamic damping factors have on the location of the peak frequency in a wind-wave spectrum. It would not be expected that wind-wave periods are conserved, since wind waves have a much broader frequency range than swell. In view of these considerations, an investigation was undertaken to determine to what extent the shoal-water correction factors computed for the San Clemente Island wave gage site can be expected to shift the frequency of maximum energy (peak frequency) of a wind-wave spectrum for a fully arisen sea.

The spectrum used in this study was that of Pierson and Moskowitz (1964). This spectrum is for a fully arisen sea condition; and is in the form of a dimensionless spectrum. That is, the energy and frequency coordinates are dimensionless quantities. In order to use the Pierson-Moskowitz spectrum, it was necessary to replace the dimensionless values along the frequency coordinate with the actual frequencies associated

with a given wind speed. This was done by use of equation (5) in Pierson and Moskowitz [1964, page 5182]. The wind speeds used in this investigation were 20 knots, 30 knots, and 40 knots. It was not necessary to alter the dimensionless energy ordinate in this investigation. The shoal-water correction factors computed for San Clemente Island for waves from the northwest, west, and southwest were applied to the sea spectra. The whole frequency range of the spectrum was considered in order to determine how the spectrum was altered and the peak frequency was shifted by application of the correction factors.

Table II presents the results of this investigation. It tabularly shows the peak frequency values before and after application of the correction factors. Figures 33, 34, and 35 are graphical examples of alteration of the fully arisen spectrum for a 40-knot sea for all three wind directions. The table and figures show that the peak frequency was shifted in most cases to a lower frequency value. The corresponding peak period shift was less than one second except for winds of 40 knots and waves from the northwest. Thus, for wind waves arriving at the San Clemente Island wave sensor, it can generally be expected that they will undergo a peak period shift of less than one second.

TABLE II: PEAK FREQUENCY SHIFT IN FULLY ARISEN SEAS DUE TO APPLICATION OF SHOAL-WATER CORRECTION FACTORS TO SENSOR SITE (DEPTH 40 FEET)

WAVE DIRECTION	DEEP WATER PEAK FREQUENCY (PERIOD)	WAVE SENSOR PEAK FREQUENCY (PERIOD)
	WIND SPEED 20 KNOTS	
NW	.136 c/s (7.4 sec)	.125 c/s (8.0 sec)
W	.136 c/s (7.4 sec)	.124 c/s (8.1 sec)
SW	.136 c/s (7.4 sec)	.124 c/s (8.1 sec)
	WIND SPEED 30 KNOTS	
NW	.090 c/s (11.1 sec)	.092 c/s (10.9 sec)
W	.090 c/s (11.1 sec)	.085 c/s (11.8 sec)
SW	.090 c/s (11.1 sec)	.086 c/s (11.6 sec)
	WIND SPEED 40 KNOTS	
NW	.068 c/s (14.7 sec)	.059 c/s (17.0 sec)
W	.068 c/s (14.7 sec)	.064 c/s (15.6 sec)
SW	.068 c/s (14.7 sec)	.067 c/s (14.9 sec)

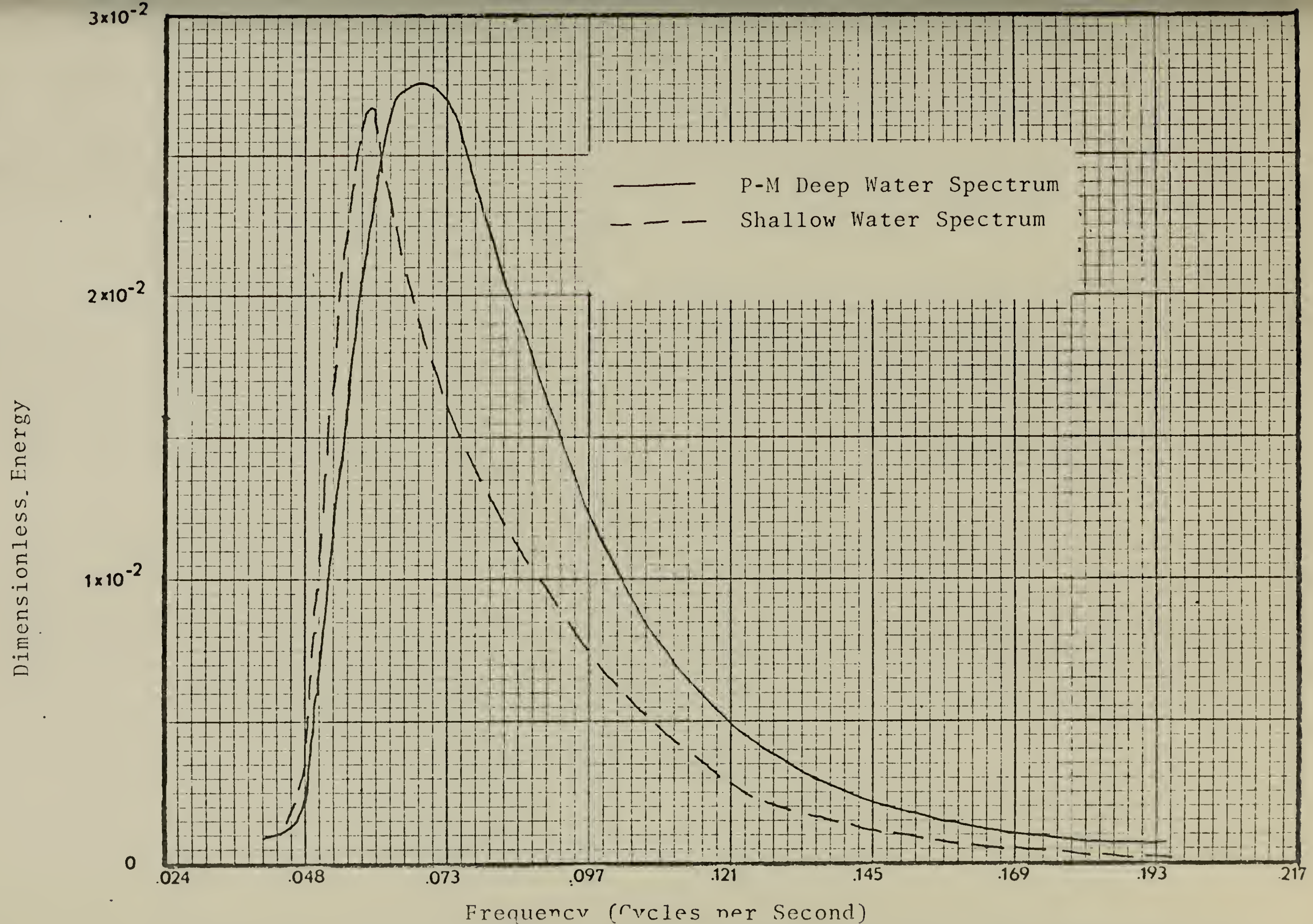

Figure 33: Fully arisen sea spectrum produced by 40-knot wind from northwest.

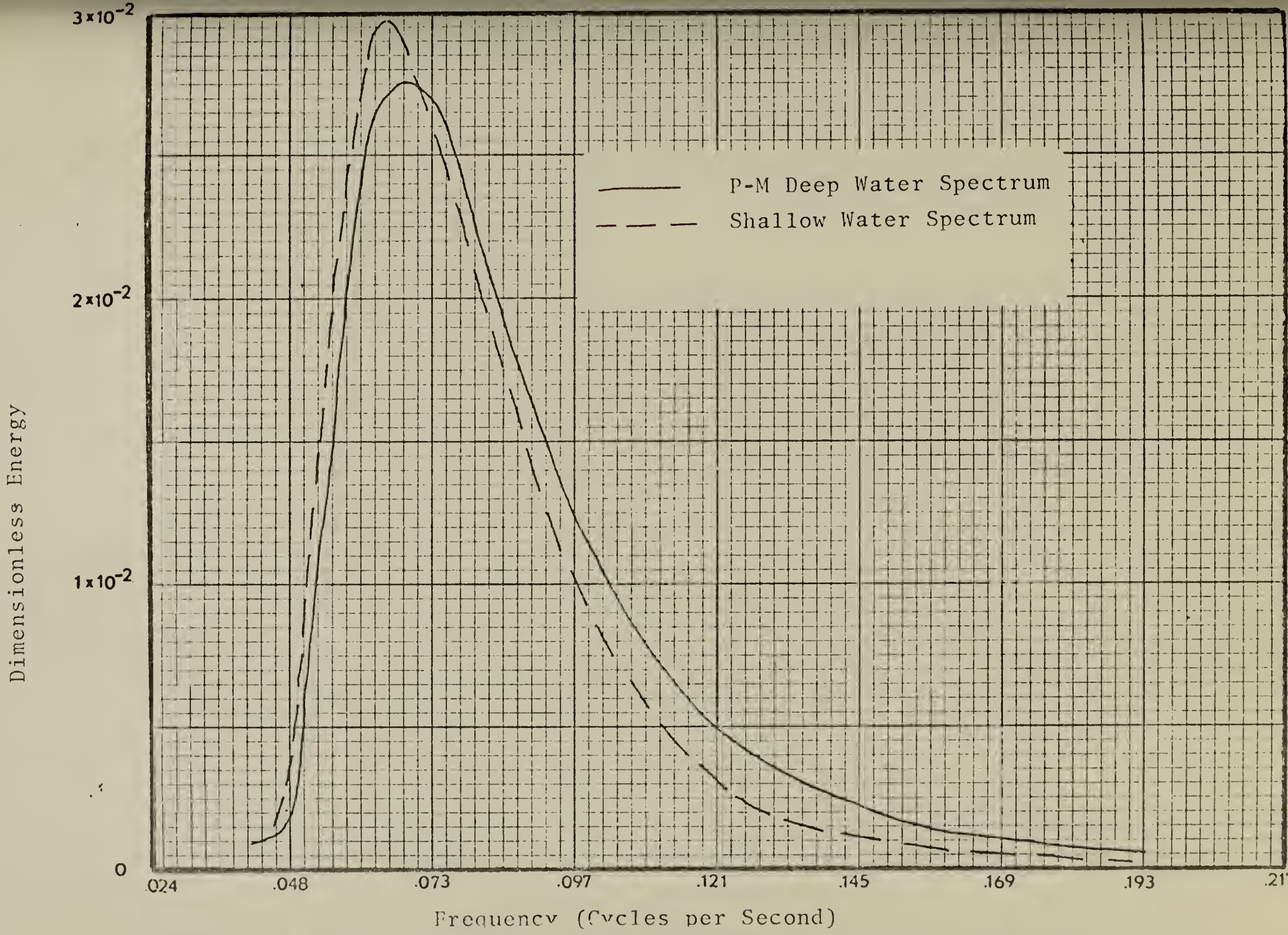

Figure 34: Fully arisen sea spectrum produced by 40-knot wind from west.

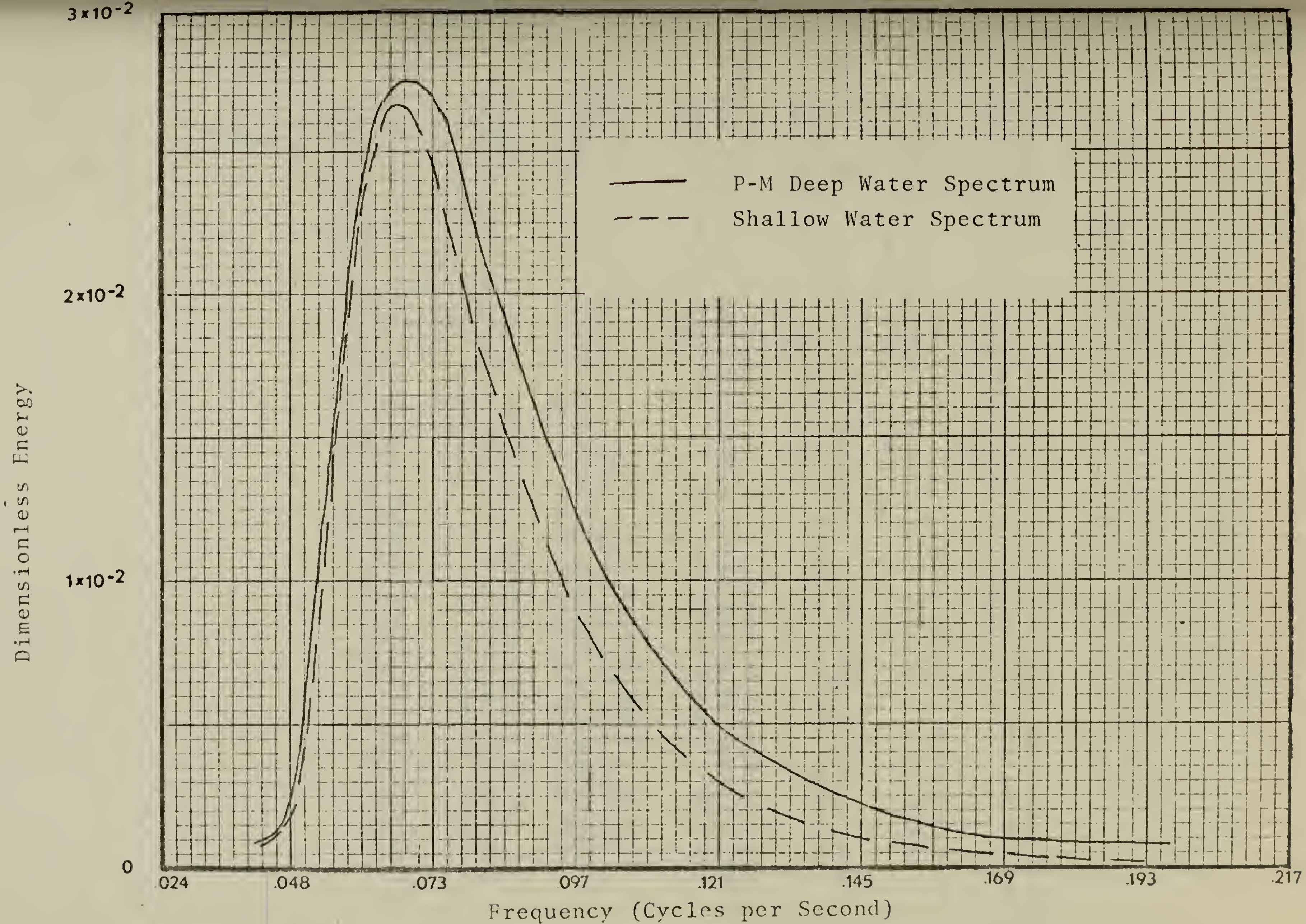

Figure 35: Fully arisen sea spectrum produced by 40-knot wind from southwest.

LIST OF REFERENCES

Anderson, J. H., "Wave Forecasting Curves Plotted from P. N. J. Co-Cumulative Spectra," Naval Postgraduate School, Department of Oceanography, Research Paper, 4 p.

Bretschneider, C. L., "Revised Wave Forecasting Relationships," Proc. Conf. on Coastal Engineering, Council on Wave Research, University of California, p. 1-5, 1952.

Griswold, G. M., "Numerical Calculation of Wave Refraction," Journal of Geophysical Research, v. 68, no. 6, p. 1715-1723, 15 March 1963.

Hubert, W. E., and B. R. Mendenhall, " The FNWC Singular Sea/ Swell Model," Fleet Numerical Weather Central, Technical Note 59, 29 p., August 1970.

Pierson, W. J., G. Neumann and R. W. James, "Practical Methods for Observing and Forecasting Ocean Waves by Means of Wave Spectra and Statistics," U. S. Navy Hydrographic Office, H. O. Pub. No. 603, 284 p., 1955.

Pierson, W. J., and L. Moskowitz, "A Proposed Spectral Form for Fully Developed Wind Seas Based on the Similarity Theory of S. A. Kitaigorodskii," Journal of Geophysical Research, v. 69, no. 24, p. 5181-5910, 15 December 1964.

Thompson, W. C., "Swell and Storm Characteristics from Coastal Wave Records," Proc. Twelfth Coastal Engineering Conference, American Society of Civil Engineers, Chap. 3, p. 33-52, September 1970.

Wiegel, R. L., "Gravity Waves, Tables of Functions," Council on Wave Research, The Engineering Foundation, Berkeley, California, 26 p., February 1954.

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13. ABSTRACT

Fleet Numerical Weather Central (FNWC) wave period and height analyses for a selected grid point were verified by comparison with wave conditions recorded by a coastal wave sensor at San Clemente Island, California. Forty-six per cent of the FNWC wave heights were within ±1 foot of the recorded heights, 75% were within ±2 feet, and 92% were within ±4 feet. The FNWC heights were found to be over-predicted by 1.0 feet relative to the recorded waves. Twenty-six per cent of the FNWC periods were within ±1 second of the recorded periods, 45% were within ±2 seconds, 66% were within ±4 seconds, and 90% were within ±6 seconds. There was no tendency for FNWC to over or underpredict swell periods, but wind-wave periods were underpredicted on the average by five seconds.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ocean wave verification						
Wave recorder site selection						
San Clemente Island wave gage						
Wave refraction data for San Clemente Island						
Sea spectrum frequency shift due to shoaling						

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